Ellis E Snyder

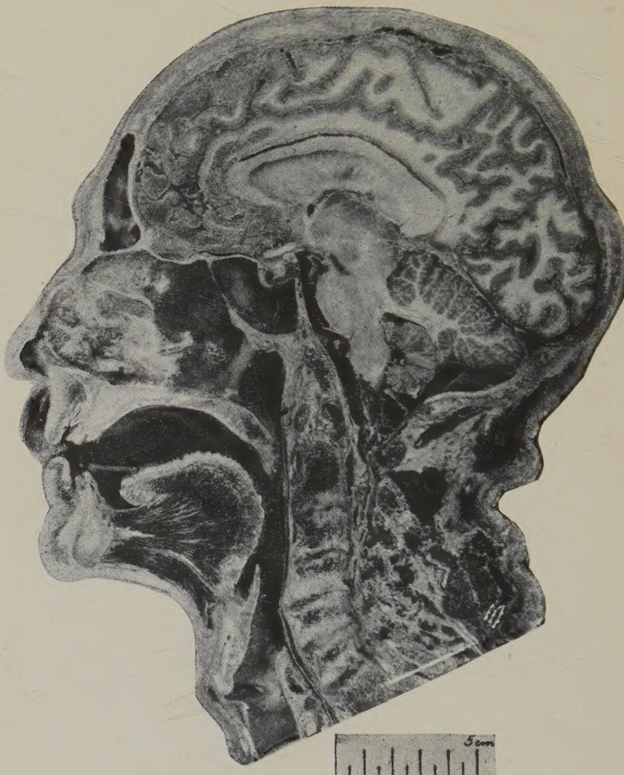

FIG. 1. (From the collection of the late Dr. S. Sisson, thru the courtesy of Dr. J. D. Grossman, O. S. U.). As fine a median section of the human head as one could wish to see. At the bottom, the larynx, or Adam's apple shows two ridges very clearly. The lower one is the vocal cord on one side; its movable attachment (arytenoid) is at the back, or right. The upper ridge is the false cord, which the present investigation would indicate, may function to impinge on, or dampen vibrations in the true cords, thereby changing the concomitant of partials, and altering tonal and vowel quality. It is aided herein by the cushion of the epiglottis which may be seen just above. Note the relation thereto, of the Hyoid Bone, and the long muscle running to the chin. The epiglottis itself may be seen sticking straight up in the air. Note the fibres of the tongue, and the manner in which the tip may be independently controlled. Even tho the lateral dimension is not comparative, the size of the nasal cavity is of interest. A 5-centimeter scale has been placed below in order to facilitate a more accurate comparison with the inclosed X-rays.

THE VOWEL

Its Physiological Mechanism as Shown by X-Ray

BY

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Music

DEDICADO
sin pedir permiso,
a
Raymond Weeks,
uno de los pocos verdaderos maestros
que he conocido, y el más amado de todos
los que he tenido.
Jorge O. R.

PREFACE

"The vowels have been more extensively investigated than any other subject connected with speech; the philologist, the physiologist, the physicist, and the vocalist, have each attacked the problem of vowel characteristics from his own separate point of view. The methods of the several classes of investigators, and the expressions of the results, are so unlike and so highly specialized, that one person is seldom able to appreciate them all. . .

"The tone quality of vowels has been more closely studied than that of all other sounds combined, and yet **no single opinion of the cause of vowel quality has prevailed.**"[1]

D. C. MILLER (1922).

The purpose of this study is to seek new light on the physiological causes of vowel quality differences. It has been thought well to precede this by a general history of what has heretofore been done in this and related fields. This survey has been incorporated under the introduction, covered in Chapter I.

It is hoped that the above quotation from Dr. Miller will suffice to show that much disagreement in regard to vowel theories still exists. Even where we do not disagree, it is often because we lack conclusive evidence one way or the other. But the author has been surprised to note the number present during reports made on the series of experiments dealt with herein[2] who assume certain of such theories to be established fact.

[1] MILLER, D. C. The Science of Musical Sounds, p. 215, 2nd ed., Macmillan, New York, 1922.

[2] Given before the American Association for the Advancement of Science, American Academy of Singing Teachers, Modern Language Association, National Convention of Teachers of the Deaf, etc.

Some of these hypotheses appear to have almost entrenched themselves in the form of dogmas, whose proponents feel hurt when anybody casts doubt on them. Many seem to be unwilling to agree with Miller. This appears to be especially true of philologists, and language or singing teachers, who have been rather hesitant to go into the scientific aspects of the problem, and perhaps somewhat too prone to accept without experiment, such theories as those involved in the vowel triangle, for example.

Too many seem unable to realize that we have been practically without facts either to prove or disprove the great majority of our theories which pertain to physiological buccal function; or that these have therefore had to stand or fall in popular esteem as their proponents and opponents varied in prominence and verbal resourcefulness. This of course necessarily had to be, because we lacked conclusive evidence as to what was going on in the mouth (or at least in the pharyngeal part of the vocal apparatus) during the course of producing either speech or song.

That is an astounding and anything but praiseworthy statement to have to make at this late period of man's existence and in this modern age of intense research. The tremendous strides forward which science has taken generally, over the past century, the extensive research made in the field of speech up to that time, and the much improved apparatus now available should have given us more information, but it just happened that nobody utilized our resources to that end.

Yet thoughtful speech is what primarily distinguishes man from the animal. To be content with unproved theories pertaining thereto under such circumstances can certainly not be considered commend-

able. But that they are unproved cannot be denied by one who notes how radically some of those theories conflict. The conflicting state of our vowel theories is shown in the fact that Miller, one of the outstanding authorities among physicists, should have made the above statement as late as 1922. And right now the majority of scientists will no doubt agree with his view that "no single opinion of the cause of vowel quality has prevailed."

If that is true, perhaps it will not be considered presumptuous for us to disagree with, or cast doubt on any number of those numerous and conflicting theories or opinions. At any rate that task devolves upon us, disagreeable as it is, for much of the evidence contained in this study tends in that direction.

Any real study of the vowel is bound to be a very complex one, because the various aspects of speech involved run into so many fields. That is one of the principal reasons why speech as a research field has for the last few decades been so sadly neglected, and still presents more vital unsolved problems to which universities could with profit turn their attention, than do many others which now receive immeasurably greater support. That is one of the principal reasons why phonetics as a serious research field, with the technical laboratories and equipment necessary for such a purpose — real laboratories of the type one ordinarily sees in departments of physics, chemistry, medical schools, etc., should be created and earnestly supported by universities.

The scope of our present knowledge makes it almost impossible for one man to master all those subjects into which speech research would lead him: physics, the various philological fields, neurology, physiology, psychology, etc., especially when he must first of all learn the principal modern languages.

The author's working bibliography covering the vowel alone, contains over 10,000 titles which bear in one way or another on its various aspects. And as the years go on, the literature becomes more and more voluminous. Our very lack of knowledge, conflicting theories, and failure to tackle the tasks before us in a systematic way, fosters that growing volume, too much of which is duplication, or superficial work. Some of the world's best scientific minds have been engaged at the task. Yet our most notable contributions have had to come from what universities might in the present day call, a "jack of all trades among scholars" (if we can use that term without implying disrespect) — Helmholtz, Ellis, Rousselot, Bell, Scripture, et. al.— men equally at home in several fields.

But this stepping over into other territory is not so easy. And it is natural that our universities should rather tend towards prevention than encouragement thereof. Then in this country at least, our institutions are highly departmentalized. And jealousy as between these divisions of a university is not entirely unknown — a condition which is not laudable, but one which is often so palpably manifest in even our foremost institutions, that it may be seriously questioned whether a "Helmholtz" for example would have been permitted to carry on his unhindered researches there. Speech, or phonetic research, has in consequence inevitably suffered, and will no doubt continue to suffer more and more acutely as the years go on, until laboratory and training facilities in phonetics, or speech research as such be provided.

That situation has seriously hampered the author in the present investigation. At times he felt he was blocked, no matter which way he turned. And now

it is with a sigh of relief that he presents what material he has. Many of the most apparent defects herein can be traced thereto. And while he has no desire to side-step responsibility, he nevertheless takes this opportunity to express the hope that petty jealousies and university red tape may in time recede sufficiently to permit more thorogoing and intensive research in the scientific aspects of speech — or if you will, in scientific phonetics.

Without the hearty coöperation of institutions, laboratories, and scientists in Europe, this study would never have been possible. So without mentioning them individually the author takes this means of expressing his very warm gratitude, for the aid they have rendered during the numerous trips made since the Summer of 1910. It is no more than fair that he name particularly Prof. Viëtor, the Abbé Rousselot, and Prof. Poirot now passed beyond. He cannot express his gratitude to Dr. Panconcelli-Calzia director of the Hamburg Phonetics laboratory; Dr. Otto Weiss Director of the Physiological Institute, University of Königsberg; M. Bull, Director of the Institut Marey, Paris; Dr. Czlumsky and Dr. Schwartz of the University Hospital, Prague; Dr. Luick and Dr. E. W. Scripture, Vienna; Drs. Struyckens, and Eijkman, Holland; Dr. Dessauer Frankfort a.M.; and Drs. Commandon and Lomon, Paris.

Finally, he expresses gratitude to Dr. Fletcher and the late Dr. Crandall of the Bell laboratories, N. Y.; Prof. D. C. Miller, Case; Prof. E. H. Sturtevant, Yale; Dr. H. B. Williams, Physicians and Surgeons College, Columbia University; Dean Woodbridge and Asst. Dean Fife, Drs. Weeks, de Onís, Muller, Gray, Bagster-Collins, Woodworth, Pupin, Gottheil, Krapp, Boas, et.al. of Columbia University. Also Dean Wm. McPherson

and the Graduate Council, the Medical School, Dr. Hugh J. Means and Miss Faye Irvin his X-ray assistant, Profs. Geo. H. McKnight and Robert Rockwood, Prof. and Mrs. Haskett and the whole force of the Photographic Division, the author's students and many colleagues at Ohio State University for invaluable services rendered on the final "check-up experiments."

The largest debt of all is owing: Dr. Edward I. Rich, and his X-ray operator Mrs. Harrop, Ogden, Utah; Dr. Heber Hancock, Portchester, N. Y., and the staffs of their respective private clinics; the Liberty Hospital, St. Louis, Mo.; and my brother, Dr. Ray M. Russell, practicing in Paris, France, for the technical help they so freely gave.

OSCAR RUSSELL.

Easter, 1928.
Columbus, Ohio.

CHARACTERISTIC VOWEL FREQUENCIES

Sir R. A. S. Paget.

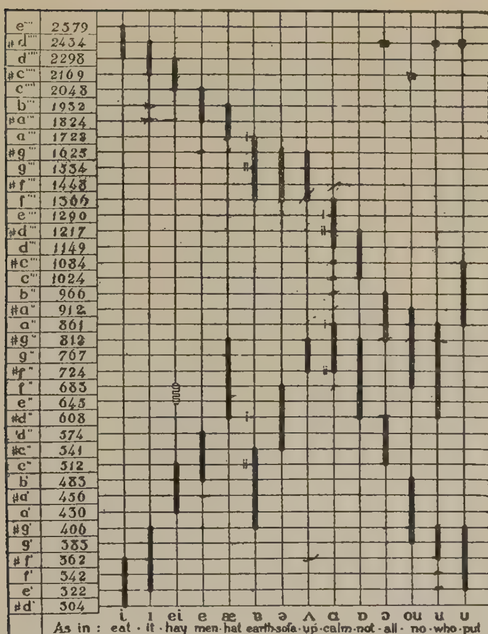


FIG. 2. Table or Chart of vowel resonances according to Sir Richard Paget.

CHARACTERISTIC VOWEL FREQUENCIES

VOWEL	*ma*	*maw*	*mow*	*moo*	*mat*	*met*	*mate*	*meet*
Whisper, *n*	1019	781	515	383	857 1890	678 1942	488 2385	391 2915
Analysis, *n*	922	732	461	326	800 1843	691 1953	488 2461	308 3100

FIG. 2-b

D. C. Miller's table showing the characteristic frequencies as he finds them in the whisper (first line) and voiced vowel curve (in second line).

CONTENTS

fused mis-application of unreliable terms — Especially true in United States, where the number of such phonetic "scholars" (?) is legion — One can be found in almost every even mediocre college teaching a class in phonetics without any, or but very little basic training in the subject, and that mostly under "scholars" (?) with about the same type of slipshod training — Even universities permit men with only literary and other remotely related training to undertake instruction in phonetic courses — Would be laughed to scorn if they undertook same in other fields — Largely accounts for vogue of defective terms — Antiquity of terms perhaps also partially responsible — For conservatism retains even what is seriously defective — Open-Closed probably first applied to jaw and lip opening — Became evident that jaw movement was purely incidental — Terms transferred to tongue — Was compromise with apparent basis in law of physics: **The larger a cavity the lower its pitch, but increased exit raises pitch** — the lower its pitch, but increased exit raises pitch — Two openings opposed in effect — Compromise use of terms therefore resulted in confusion — And X-ray now shows tongue opening to be almost as incidental as jaw — Hence should discard terms "Open-Closed."

Examination of terms "Narrow-Wide"— Quite different in theory to above — Just as unreliable, as shown by numerous lateral dimension palatograms herein.

Examination of terms" Tense-Lax"—Total air volume resonator, or cavity tone theories not entirely sustained in analysis of above experiments — Tension of muscular surfaces indicated to be of more importance than heretofore credited — Hard surfaces create "ringing" or "metallic" tones by favoring high partials — Soft surfaces suppress high partials and thereby create "mellow" "dull" or even "dead" tones — Hence terms "Tense-Lax" more applicable — But are only relative, and based on a theory which may yet be exploded like other physiological theories — Safer to rely on acoustic terms describing what we hear — That represents a fact — Author favors: "metallic-mellow; clear-dead; bright-dark; ringing dull;" for quality dscription. Or "high-pitched-low pitched" to indicate basic acoustic characteristic, as evident in one accepted law of physics.

ILLUSTRATIONS AND TABLES

FIGS. PAGE

Vowel Triangle Tongue Positions

Another Pronunciation Same Subject

Lateral Sections on Subject 291 Used for Clay Models

My Early X-Rays

My Early Attempts to Prove Triangle

Total Area and Lip Spread Also on Figs. 489-523

THE VOWEL

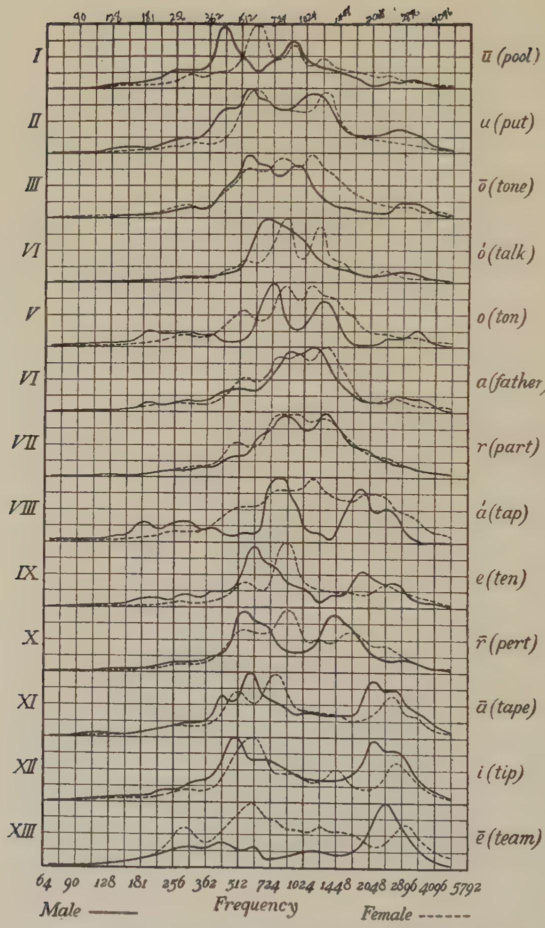


FIG. 3. Vowel Characteristic Frequencies According to the late Dr. Irving B. Crandall. Analyses of vowel sounds. Relative importance of the amplitudes at different frequencies taking into account the sensitiveness of the ear.

CHAPTER I

HISTORICAL

Vowel researches of any value to us are strictly a modern product. Most of what was published prior to Bonet's[1] time is but an unsupported expression of mere opinion, or what is essentially the same thing, a statement of what the individual thought he felt or saw in his own enunciation. Real research was not begun until the advent of what we know as modern science. That was particularly true of the contributions in physiology or anatomy, physics, psychology, philology, and such other divisions of science as deal with speech; and this aspect of research we now group under the one term —"phonetics."

Phonetics, however, is not entirely a modern science. In a sense, the earliest Babylonian who imagined the use of an ideogram as a phonogram was a phonetician. However, the deliberate investigation of the scientific aspects of speech-sounds, of which fully half are generally vowels, was hardly carried out by the ancients, though indeed Aristotle is said to have considered it.

The ancient grammarians regularly gave some consideration to the differences between vowels and language in general. The Alexandrian Greeks made a classification that was copied by the Romans and remained traditional for over 2000 years. The classes were vowels, semi-vowels (i.e. voiced consonants), and consonants (i.e. voiceless consonants). They recognized diphthongs, and also had terms for liquids, nasals, mutes, aspirates, etc., and divided the stops into labials, dentals, and gutturals, according to the point

[1] See p. 11.

of articulation. For the vowels they used certain adjectives (e.g. pinguis, exilis) to distinguish qualities of sound, but did not discuss how the difference was made. Beyond these points they rarely went. The Sanskrit and Arabic grammarians are said to have discussed vowels and speech-sounds with more insight, but in this regard they had no influence on Western scholarship.

Even as late as the sixteenth century, or as a matter of fact right at the present time, a large part of what is published is but mere commentary and record, of speech as the individual thought he heard it or saw it produced. A typical example of these commentaries is noted in the remark of Scaliger on the vowel *a*: [1]

"... neque re ulla eget alia quam hiatu oris solo sine ullo caeterorum motu instrumentorum."

But commentaries may for our purpose be disregarded, since this study is confined to an attempt to find out what is happening to the physiological organs in vowel production, and that more particularly in those regions where we have almost no power of sensing what happens. So likewise may studies in the historical phonetics of particular languages, usually and more properly called phonology.

Prior to the sixteenth century, most investigations of research scholars which concerned the vowel had to do with some kind of attempt to construct artificial talking automatons. Sylvester II (a pope 999-1003) and Albert le Grand (b. 1193 or 1205, and d. 1280) are among those world famous men who engaged in such efforts. Of the latter we read: [2]

"C'est probablement à Cologne qu'il fit son automate, doué du mouvement et de la parole que St. Thomas d'Aquin, son disciple, brisa à coups de bâton, à la première vue, dans l'idée que c'était un agent du démon."

[1] De causis ling. lat., I, 38.
[2] See Michaud's Biographie Universelle.

But as to the attitude he took towards these experiments, the same author says:

". . . le goût qu'il avait pour les expériences, et pour ce qu'il appelle lui-même des opérations magiques." (voy. Albert Magn. Op., t 3, de An., p. 23 Lugd., 1651. See also Naudé Apologie des grands hommes soupçonnés de Magie.)

That statement indicates the spirit of the times — the spirit which led to experimentation of this type. It took a man like Albert le Grand, with probably a good sense of humor, coupled with an insatiable curiosity, to proceed to such a task. But it must be remembered that he was also a solid churchman and philosopher. In this sense he was perhaps the greatest man of the period. As is well known, his classes at the university in Paris became so famous that the buildings did not provide enough room for the students who flocked from all over the world to hear him. And these were his lectures on the physics of Aristotle. But people appear to have been very superstitious and it was inevitable that many a clever individual should take advantage of their credulity. We know that many of those talking automatons, heads, or statues, were fakes. This had been true since the days of Greek and Roman oracles. They generally involved the trick we have discovered in excavations of one of the temples at Pompeii, where the priests arranged a hidden tube, often extending some distance in order to carry out the talking hoax. Down to the days of Napoleon the exhibition of fake automatons of all kinds was common. Even as late as the time of v. Kempelen we find him constructing a fake chess-playing Turk automaton, which he carried along with his well known artificial speech machine.

One of the cleverest fake speaking machines allowed all who cared to inspect the interior mechanism of wheels, tubes, bellows, etc., but of course observers

for a long while failed to discover that one of the latter housed a dwarf, who, even when it was being moved around, thus made the thing talk by means of a tube to the mouth.

So we even come to suspect this earlier artificial "talker" of Albert le Grand, knowing his spirit of deviltry, and lacking as we do, any careful description as to how it functioned.

We have reason to imagine, however, that enough was known at a very early date, as to how artificial

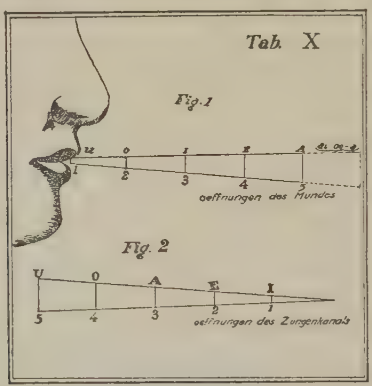


FIG. 3-b. Kempelen's Conception of Vowel Cause.

vowels and speech might be produced, to enable the ancients to construct make-shift un-faked talking automatons. Since Kempelen reproduced some of the fakes, he may not have been unacquainted with their legitimate efforts. He called attention[1] to the fact that a speaking reed tone passed into any open, wide mouth cavity, would produce a good imitation of *a*; and if the cavity were very narrow mouthed, it would speak *u*; whereas an intermediate opening would give *o*. He had trouble with the front vowels but we note that three of the five could be readily imitated with

[1] KEMPELEN, W. Mechanismus der menschlichen Sprache (1791) Wien.

sufficient accuracy to make guessing possible. If an artificial head were constructed with movable jaws or lips the mechanic might easily "fall into the reproduction" of the three vowels *a, o, u*. And the consonants *m, b, p,* and *f,* are quite readily reproduced. Hence a large selection of words would be easily possible.

Of course we have no means of knowing whether Kircher[1] (1650) knew of, and had in mind the success

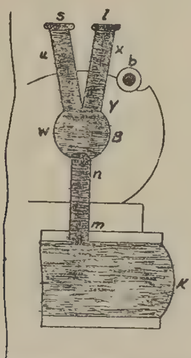


FIG. 4. Section of Kempelen's Artificial Speech Machine, showing some of the consonant tubes. The finger tips of one hand were kept over the mouths of tubes s and l. By opening them in various ways he got different consonants. The tube b which entered the large horn C allowed the unvoiced air current to pass into the latter making it possible to imitate the whispered vowel. K indicates the bellows.

of Albert le Grand, or talking heads of greater antiquity still; but his reference to the possibility of constructing such a head and that, occurring in his discussions of the ancients, makes one imagine that his idea was culled from perhaps even classic times. This looks all the more likely, in that he acknowledges that he did not himself construct such a one, but merely

[1] KIRCHER, Athanase. b. May 2, 1602. Another very interesting scientist of early prominence. He is credited with the invention of the magic lantern.

proposed to do so for the amusement of Queen Christine of Sweden.[1] We lean more strongly to that viewpoint when we note the severest criticism of his work to occur in "Musici veteres grœci" written by the famous Meibom. In comment on Kircher and his proposal we read: [2]

(In his work) "On y trouve. . . des choses aussi savantes que curieuses, sur la musique des anciens. Kircher y assure (livre 9) qu'on peut fabriquer une statue, parfaitement isolée, dont les yeux, les lèvres, et la langue auront un mouvement à volonté qui prononcera des sons articulés, et qui paraîtra vivante." [3]

We must needs pass to the next century, however, before we find any actual description of such artificial talking machines. The creation of the French Academy of Sciences [4] had done more than we can now appreciate to eliminate the fake element, in this aspect of vowel study. Anything which was presented there had to have some substantial foundation in fact, and it is from this source that we hear of the first artificial talking machine which has any scientific interest for us. There were several of them, all constructed by the extremely modest and retiring Abbé Mical, in Paris. They were in line with some of his other efforts, and the first might well have been constructed any time between 1750 say, and somewhere around 1780. Weiss wrote of him:

"D'un caractère doux et modeste. Il construisait d'abord deux automates jouant de la flûte, et successivement plusieurs autres, de manière à former un concert entier. . . L'inventeur le brisa par des motifs. . . que le redacteur des *Mémoires secrets* (t. 26, p. 215) nous apprend. . . fut parce

[1] KIRCHER, Musurgia universalis sive ars magna consoni et dissoni in X libros digesta, Rome 1650, 2 vol. in-fol; Amsterdam 1662, in-fol.

[2] MICHAUD'S Biographie Universelle.

[3] See also Phonurgia nova de prodigiosis sonorum effectibus et sermocinatione per machinas sono animatas (Kempten) 1675 in-fol. and SCHOTT, P. Magia universalis, t. 2, liv. 3.

[4] Founded with 68 members in 1666.

qu'on lui avait reproché d'avoir frabriqué lui-même des figures nues.

"L'abbé Mical construisit ensuite une tête d'airain qui articulait assez distinctement de petites frases;

This latter statement is interesting, because we know

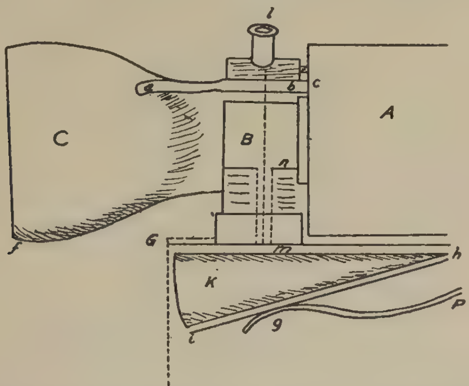


FIG. 5. Side View of Kempelen's Artificial Vowel Machine (1791) Duplicated half a century later by Wheatstone, whose reproduction may still be seen in King's College. Sir Richard Paget who accomplishes such unusual results with his own resonators, gave a scientific demonstration with it not long ago. K = Bellows. A = Wind Box. C = Vowel Horn about as big as the palm of the hand. When the mouth of the latter was left completely open, it produced *a* (ah) just as almost any size open horn would. Kempelen states that he accomplished *o* (oh) by using the hand to cover the horn mouth by about ½. If he almost completely closed it, the resultant was heard by comparison as an *u* (oo). But he notes that the vowel is only correctly interpreted where heard by comparison with the others, and he acknowledges relative failure with the "front" vowels such as *i* (peep). About the same thing might be said of almost any open horn of any shape or dimensions whatever.

that Albert le Grand's talking machine consisted of a head of the same type. He continues:

"mais un curieux auquel il avait montré cette machine, en ayant fait un pompeux éloge dans une lettre insérée au *Journal de Paris*, il la brisa indigné qu'on eût révélé l'existence d'un ouvrage qu'il jugeait trop imparfait pour mériter l'attention.

If one had access to files of the "Journal de Paris" he could find the date of this article. It would probably establish the Abbé as being the first such legitimate constructor of whose work we have intimate knowledge. Because of his retiring nature and excessive modesty, the idea of presenting his machine before the Academy does not seem to have occurred to him until Kempelen appeared in Paris with his set-up.[1] When we know Mical's nature we inevitably conclude that friends prevailed upon him. Then too, that very modesty was probably what kept him from publishing, if we might judge by the above incident. Kempelen published his work in 1791. The Abbé's was presented before the Academy in 1783. Of the two, his claim to priority must therefore be undisputed, and we cannot help but feel that Wheatstone did him a double injustice in propagating a story which did violence to his known character, and in belittling his claim to priority. The date above is established in the annals of the Academy, even though that in the "Journal" could not be found. Weiss gives it in a continuation of the above quotation, as follows:

". . . Cependant à la prière de ses amis, il reprit son travail et fabriqua deux nouvelles têtes parlantes qu'il soumit en juillet 1783 á l'Acad. Vicq d'Azyr fit un rapport le 7 sept. suivant sur ces étonnantes machines; il reconnut que l'abbé Mical avait atteint en partie le but qu'il s'etait proposé et lui donna beaucoup d'encouragement. Mais le gouvernment, sur le rapport du lieutenant de police Lenoir refusa d'acheter ce chef d'oeuvre de mécanique.

". . . on peut croire que la machine de l'abbé Mical était supérieur à celles"

referring to those which had been constructed prior to his time, especially one at Dresden by J. Valentin Merbiz (d. 1704) evidently a fake,

"et qu'elle emportait même sur celle que Kempelen montrait

[1] In 1783.

dans le même temps à Paris sans partager l'enthousiasme qui dut beaucoup affliger le bon et modeste abbé Mical."

This statement coming from Weiss is probably to be credited without necessity of discounting from a sense of exaggerated nationalism, such as probably led many German scholars to ignore Mical, and attempt to fix all priority rights on Kempelen.

Rivarol gave the following description of the apparatus, or heads which Mical constructed:

"Il. . . a appliqué deux claviers à ses têtes parlantes; l'un en cylindre, par lequel on n'obtient qu'un nombre déterminé de phrases, mais sur lequel les intervalles des mots et leur prosodie sont marqués correctement;

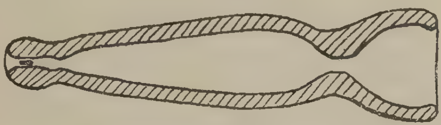


FIG. 6. Paget's Resonator for ə (earth) Pitches 1534/512

This was evidently some "music box" or "player piano arrangement" for tripping off the respective sounds in the proper time and order. In that sense, his apparatus was apparently far superior to any produced since. He continues:

"l'autre clavier contient, dans l'étendue d'un ravalement, tous les *sons* et tous les *tons* de la langue française, réduits à un petit nombre par une méthode ingénieuse et particulière à l'auteur. Avec un peu d'habitude et d'habileté on parlera avec les doigts comme avec la langue, et on pourra donner au langage des têtes la rapidité, le repos et toute la physionomie enfin que peut avoir une langue qui n'est point animeé par les passions. Les étrangers prendront *la Henriade* ou *Télémaque*, et les feront réciter d'un bout à l'autre, en les plaçant sur le clavecin vocal comme on place des partitions d'opéra sur les clavecins ordinaires." [1]

A more specific description is found in the report of the commissioners of the Academy of Sciences:

[1] RIVAROL, Œuvers de. t. 2, p. 230 ff. *Lettres à M. le président de. . . .*

"Les têtes recouvraient une boîte creuse, dont les différentes partis étaient rattachées par des charnières, et dans l'intérieur de laquelle l'auteur avait disposé des glottes artificielles de différentes formes, sur des membranes tendues. L'air, passant par ces glottes allait frapper les membranes, qui rendaient des sons moyens ou aigus, et de leur combinaison résultait une espèce d'imitation trés imparfaite de la voix humaine."

The last statement is about the kind of judgment the present author would pass on any present day apparatus for the artificial reproduction of vowels (if he were called upon for a perfectly frank opinion), and it has been his good fortune to listen to the great majority of those made public during the last century. So in this aspect of vowel studies, it can hardly be said that we have made any astounding progress since the days of Mical. Later on we shall have several occasions to refer again to Kempelen, and Kratzenstein the Russian who preceded him with an artificial vowel machine. For the time being we may pass immediately to a more important aspect of vowel studies.

* * * *

The first actually scientific, and purposeful vowel studies which might have been of service to such a study as the present one, seem to have resulted from work with the dumb. The noted father of this movement was a Spanish Benedictine monk, Pedro Ponce de León, who died at Oña in 1584. He sought to devise a method of teaching deaf-mutes to speak and is credited with actually succeeding. To have accomplished this result he must have given a large part of his attention to the vowels for 50% of Spanish speech sounds are vowels.[1] Ponce's method apparently con-

[1] See NAVARRO TOMÁS, T. Manual de Pronunciación Española, 3d ed. Madrid 1926, p.

This aspect of Spanish pronunciation cannot have changed materially during the period elapsed.

sisted in pointing out the movements of the speech organs in connection with the letters. The exact details are not known. He is said to have written a book on his method, but it has been lost. Eye witnesses say that one of his pupils, after attentively considering the movement of the lips, repeated perfectly words pronounced in a language he did not know. A French writer remarks:

"ce fait singulier est attesté par un témoin bien impartial, un anglais, sir Kenelm Digby."

Ponce's reputation was very great; in his epitaph we read:

"in hac (virtute) praecipue floruit, ac celeberrimus toto orbe fuit habitus, scilicet mutos loqui docendi."

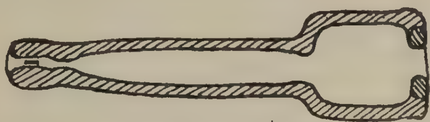


FIG. 7. Paget's Resonator for *a* (calm) Pitches 1366/724

In the oldest book extant on teaching deaf-mutes, "Reducción de las letras y arte para enseñar a hablar los mudos" by Bonet who was a disciple of Ponce, we note a continuation of the movement.[1] In Part II of his book he explains the physical formation of all the Spanish sounds.[2]

Another of the early treatises[3] of interest to those considering scientific aspects of the vowel has sometimes been credited to John Wallis, Savilian Professor of Mathematics at Oxford (and afterwards Bishop), who has as a preface to his English Grammar published in

[1] BONET, Juan Pablo. Reducción de las letras y arte para enseñar a hablar los mudos, "Madrid 1620.

[2] Brücke, Ernst. Grundzüge der Physiologie und Systematik der Sprachlaute f. Linguisten u. Taubstummenlehrer 1856 p. 5.

[3] There is a legend that the venerable Bede taught a deaf-mute to articulate, but it cannot be confirmed.

1653 a "Tractatus grammatico-physicus de loquela,"[1] which he undertook to apply to Latin, Greek, Hebrew, Aarbic, Persian, German, French, Welsh and Gaelic. He was probably quite independent of the Spaniards, as he knew no Spanish. He says himself:

"Nescio an quispiam me prior totam loquelae rationem conjunctim et systematice tradiderit."

Although advancing some wild theories, such as the close connection of English and Hebrew, he has many sound ideas.

"Vocum articulatio tunc incipit postquam spiritus extra laryngem pervenit, et naribus, ore, lingua, labiis fere tota perficitur."

In view of West's[2] recent conclusion, it is interesting to observe the theory Wallis had that pitch was partly determined by the trachea. There seems to be no doubt that Wallis taught two deaf-mutes to speak:

"Studiis quibus primus se dedit (Wallisius) inductus est ad putandum omnem sonorum varíetatem effici per mutationes quosdam organorum vocis, quae autem apte vereque inquisitione determinari possent. Unde hanc opinionem concepit: surdos eosdem et mutos surmonem doceri posse. A quibusdam pertinaciter rogatus, incepit ita docere virum natura mutum et surdum (cui nomen Daniel Walley de Northampton). Opere incepto, anno millesimo sexcentesimo sexagesimo, post paulo plus uno anno tranacto discipulum docuerat plane enuntiare omnia verba, non exceptis difficillimis extranearum linguarum, atque anglicanam liguam satis expedite intelligere. Idem effecit anno sequente, et virum alterum, Alexandrum Popham nomine, similiater edocuit."[1]

Three other writers of the same period who may be called precursors in the field where Helmont,[3] (1667) the defects of whose work were so clearly pointed out

[1] WALLIS, Tractatus grammatico-physicus de loquela, 1653.

[2] WEST, Robert. *The Nature of Vocal Sounds.* Quarterly Journal of Speech Education. Vol. XII. Nov. 1926.

[3] HELMONT, F. M. van. Naturalphabets der Heiligen Sprache (1667) nach dessen Anleitung man auch Taubgebohrne verstehend und redend machen kan. Reprinted in Vox. beginning Heft 3, 1916. See criticism in

KEMPELEN, Mechanismus der menschlichen Sprache 1791.

by Kempelen, Bishop John Wilkins,[1] (1668) and Dr. Holder[2] (1669). However, in so far as the latter two showed any penetration into the production of vowels, they doubtless owed it to Wallis. Most of Wilkins' disquisition was not concerned with the vowel and its mechanism at all, but with a curious scheme of ideograms.

Another investigator of vowel phenomena in connection with teaching deaf-mutes was J. C. Amman, (1692) a Swiss living in Holland.[3] And throughout the eighteenth century it seems to have been mainly in this connection that phonetics was studied. And of course the vowel is always vitally involved and must make up a large part of such work. The most famous

FIG. 8. Paget's Resonator for Vowel ʌ (up) Pitches 1625/812

deaf teacher in this period, and the one who influenced our present methods most profoundly, was the Abbé de l'Epée[4] in France (1774).

* * * *

We may now turn to those who might be considered precursors of the scientists who developed the various aspects of our modern vowel theories. In some cases it would seem that we have erred in not giving them the actual credit.

Viëtor is very prone to trace priority claims for all

[1] WILKINS, An Essay toward a Real Character and a Philosophical Language, London 1668.

[2] HOLDER, The Elements of Speech, an Essay of Inquiry into the Natural Production of Letters, 1669.

[3] AMMAN, J. C. Surdus Loquens, 1692. Dissertatio de Loquela, 1700.

[4] L'abbé de l'EPEE. Sourds et muets, Paris, 1774. Institution des sourds et muets, Paris, 1776. Veritable manière d'instruire les s. et m., 1784.

possible phonetic theories and phenomena to some German scholar. If we accepted his word for it, credit for our modern cavity-tone theory, should probably go by priority to Reyher (1679) : [1]

"Die Resonanzen (Eigentöne) des Mundraumes für die einzelnen Vokale sind vielfach zunächst meistens auf Grund der geflüsterten Vokale bestimmt worden, zuerst wohl von Reyher." [2]

Helmholtz (Ellis translation) erroneously cites the date for Reyher's work as 1619, and that of Hellwag[3] as 1710. The latter's "Dissertatio. . . de formatione loquelae" appeared in 1781. Hellwag was among the first to fix definite whispered pitches for each of the five principal (or shall we say the Latin) vowels.[4] Besides studying comparative qualities and devising schemes for indicating articulation he made physiological observations which involved the use of cadavers and a study of his own pronunciation. He also seems to have made use of a process somewhat akin to our modern palatograms (which we owe to the Abbé Rousselot[5]). We refer to Hellwag's studies of 1780, 1783, left us in manuscript form, containing his comment on the "berühmten Joh. Beck" with the removable artificial nose and palate. He is not even mentioned by Lepsius or Brücke, but in 1863 Thausing expressed the idea that Chladni and Du Bois-Reymond got the idea of the triangle from him.[2] Viëtor has elaborated on this thesis, crediting him particularly with that form of the scheme which placed the *a* at the bottom

[1] REYHER, Mathesis Mosaica, 1679.

[2] VIETOR, Elemente der Phonetik 6th ed. p. 31-32 Amm. 1.

[3] HELLWAG, C. F. Dissertatio inauguralis physiologico-medica de formatione loquelae (1781) Tübingen.

Ms. Entstehung der Buchstaben aus der Ubereinstimmung ihres Lauts hergeleitet, (1780)' Göttingen.

Ms. "Zum eigenen Gebrauch" (1783).

Compare VIETOR op. cit. p. 48-49, 33. Helmholtz (Ellis) p. 108-9.

[4] See TRAUTMANN, Sprachlauten, 1884, p. 29 ff.

[5] Oacley Coles seems to have originated dental false palates in 1871.

and the *i* and *u* at the upper extremities; and is therefore wont to speak of this scheme as the German triangle.

The process of whispering in order to ascertain the natural period of the cavity tones was also used by Flörcke,[1] 1803-4, and Olivier[2] 1804. But it was Donders who appears to have perfected the technique as we now know it.[3] This process coupled with that of percussion in its various forms remain the two most common physiological means of ascertaining the pitch for the principal vocal cavities; and both are still very effectively used by such well known investigators as Sir Richard Paget. That involving percussion is of rather later development, being a contribution which we owe mostly to Alex. Graham Bell[4] and F. Auerbach.[5]

FIG. 9. Another Paget Resonator for *a* (calm) final shape

These processes, and this aspect of vowel investigations, are dependent upon what the ear hears. And after all, that is the essential. For to us, the vowel is non-existant except as we hear it. This fact has been

[1] FLORCKE, Neue Berliner Monatschrift, Sept. 1803, Feb. 1804.

[2] OLIVIER, Ortho-epo-graph. Element. W. pt. III, p. 21, 1804.

[3] See HELMHOLTZ (Ellis Trans.) Sensations Tone p. 108 b.

DONDERS, De physiologie der spraakklanken Utrecht 1780.

Ibid. (transl) *Zur Klangfarbe der Vokale.* Arch. f. holländ. Beiträge z. Heilk. m 1861. III 446.

Ibid. (same title) Ann. d. Phys. u. Chem. 1864 CXXIII 527.

[4] HELMHOLTZ op. cit. cf. BELL, Am. Jour. Otology, vol. i. July, 1879.

[5] AUERBACH, F. Wied. Ann. 3, 152, (1878). Pogg. Ann. Erg. Bd. 8, 177, 1876.

repeatedly stressed by such scholars as Auerbach, and Scripture; particularly when considering objections to those studies which are based on pure mathematical analysis of recorded waves, and other like investigations when entirely divorced from manifestations of hearing.

* * * *

We may think of these tones which the ear hears as accompanying the fundamental (or glottal tone), either in terms of independent or harmonic relationship between the two. But there can be no question that the ear hears some tonal quality as being present to distinguish vowel from vowel. At least as early as 1726, Rameau [1] heard and described these superimposed, or amplified, or accompanying tones. By the time of the epoch-making experiments of Young [2] in 1800, this aspect of these theories had been fairly well stabilized. Of course the law governing the vibration of strings, as we know them in musical instruments, had been known at least as far back as the time of Pythagoras (circa B. C. 540-510): viz. "when strings of different lengths but of the same make, and subjected to the same tension, were used to give the perfect consonances of Octave, Fifth, or Fourth, their lengths must be in the ratio of 1 to 2, 2 to 3, or 3 to 4 respectively. And as his knowledge was probably partly derived from the Egyptian priests, it is impossible to conjecture in what remote antiquity this law was first known." But it was Young who devised the optical means of demonstrating that in a vibrating string, we have present not only the fundamental or full length vibration, but that of its half length or first octave, and successively higher multiples corresponding to its respective upper

[1] RAMEAU, Ph. N. Système de musique théorique, Paris, 1726. (See especially the preface).

[2] YOUNG, Th. Philos. Transact. Roy. Soc. London, 1800.

partials. Then in 1843 Ohm[1] organized this information in the form of the law which now carries his name.

All our modern scientific conceptions as to the function of the glottis in the production of the vowel and the creation of voice, seem to have their origin in the investigations of two famous French physicians. The first of these two statements or theories as to function came from Dodart,[2] who was born in Paris, 1634. Of him we read:

"Il avait le projet de composer une histoire de la médecine; mais prévenu par Leclerc il travailla à celle de la musique, et les mémoires qu'il communiqua à l'Académie sur la formation de la voix en sont en quelque sorte l'introduction; il y compare l'organe vocal de l'homme à un instrument à vent, système adopté dans les écoles jusqu'en 1742."

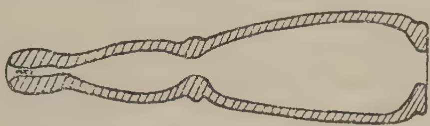


FIG. 10. Paget's Resonator for ɔ (all) Pitches 406/861

While Scripture does not so indicate it, this theory of Dodart would apparently be considered the forerunner of the "puff theory" whose inception Scripture attributed to Willis (1832). This postulate would apparently call for the vocal cords to function in much the same manner as the lips of the mouth do when blowing a trombone, or trumpet. In other words they would open and close in such a manner as to throw out intermittent puffs of air at rapid and regular intervals, having different forms, yet creating alternating waves of condensation and rarefaction, which would stimulate the cavities above. And the whole

[1] OHM, G. S. Pogg. Ann. 59, 497 (1843) 62. 1 (1844).

[2] DODART, Mémoires of French Acad. Science. Paris (1700). (see comment) RENAULDIN in Biog. Univ. on Dodart, Denis.

sound would in its turn be concentrated, megaphone-like, or be amplified by the cavities. As stated in the above quotation, this theory held sway until 1742. It was in 1741 that Ferrein published "De la formation de la voix de l'homme." Renauldin, from whom the above comment on Dodart was taken, summarizes the two views in the words:

"Dodart avait comparé l'organe vocal à un instrument à vent: Ferrein voulut y trouver toutes les propriétés des cordes sonores."

This theory of Ferrein's[1] spread rapidly and right down to our time practically dominates most of our conceptions which revolve around theories to account for vowel quality differences. Ferrein's theory is another of those which have been erroneously credited to Helmholtz. We refer of course, only to the function of the glottis in producing human speech and song. That aspect of the theory was advanced, defended, and clearly understood 100 years before the time of Helmholtz (1859). The variation in pitch of the cavity tone by altering the length of the tube in wind instruments was also well understood.

All the fundamental facts involved in the theory of vowel production, were therefore common property 50 years before even Kempelen (1791) published his work, and well understood among the scientists of that city for at least several decades before he arrived in Paris to exhibit his fake automaton and speech producing machine. Justice would seem to require that we credit the inception of the **"glottal puff theory"** to **Dodart,** and of the **"vocal cord vibratory"** or **"partials" theory to Ferrein.**

It was in 1830, almost 100 years after Ferrein, when

[1] **FERREIN**, Antoine (b. 1695). De la formation de la voix de l'homme, (1741) in l'Histoire de l'Açadémie, etc. See also Sur les mouvements de la mâchoire inférieur (1774). Sur les mouvements des deux mâchoires (1744).

Willis [1] published his article on vowel sounds. In it he appears to have laid down for the first time a concise and well ordered statement of the laws which govern cavity-tone function, and adduced experimental evidence going to prove how they operate to alter vowel quality. This question is dealt with in more detail later on. There we have called attention to the fact that the **"cavity tone theory"** should be credited to **Willis.**

We mentioned above the contribution of Young. He made it possible to demonstrate the existence of partials in the complex tone produced by a vibrating string. Where Ferrein's theory was accepted, the complexity of the partials present in the human voice must therefore have been understood as early as 1800.

The facts of simple resonance had apparently been known for ages. But 37 years passed after Young's epoch-making experiments before Wheatstone [2] published his article on multiple resonance. This was a clear and lucid statement of the overtone theory, and is reproduced in detail in the chapter herein on "vowel theories." The facts make it very clear that the **"overtone" theory** should be credited to **Wheatstone** and not to Helmholtz, as is so often ignorantly done. This aspect of the "resonance theory" should also be credited to Wheatstone, since the two terms are in that respect synonymous. Of course that does not involve those aspects of the resonance theory which have to do with the manner in which the ear functions in order to interpret the complex vocal and instrumental sounds which it hears. Wheatstone had nothing to do with that.

[1] WILLIS, Wilfrid. On vowel sounds, and on reed-organ pipes, Trans. Camb. Phil. Soc. (1830) III 231.

[2] WHEATSTONE, Chas. Sir. Westminster Review Oct. (1837) p. 27. (See Chap. III, page 27 herein).

Much of this information dates back to 1683, the time of Du Vernay. By the time of Cotugno[1] in 1760 very considerable information had been gathered as to the function of the inner ear. This was added to by Le Cat (1767), Carus (1828), Claudius (1858), Helmholtz (1862), MacKendrick (1873), König (1876), Urbantschitsch (1881), certain important counter or different theories, by Bonnier (1895), Hurst (1895), and a mass of other facts, interpretations, experiments, analyses, theories, and arguments pro and con, which continue piling in on us right down to the present day, as with Ewald (1906), Wittmaack (1907), Zwaardemaker (1905), Siebenmann and Yoshii (1908), Fletcher and Wegel (1925), etc., etc.

This hurried historical summary of early studies, of, or rather attempts to ascertain, what made differences in vowel qualities, brings us to what we may perhaps deem a starting point for purposes of the present study. We need not go into a detailed consideration of modern studies. They are very generally known and have been summarized time and again in recent works which are easily available to all. Then too, they are so voluminous, that even a cursory consideration would without doubt make a fair sized volume and provide the material for a good study in and of itself. That is, if it aimed to be at all satisfactory.

We have herein, therefore, been content for the most part, with textual references to these latter, and have paused for a more detailed consideration of but two of the most vitally involved in the present series of experiments.

[1] COTUGNO, De aquaeductibus auris humanae internae Naples, 1760.

CHAPTER II

TWO BASIC VOWEL THEORIES
WILLIS
CAVITY-TONE THEORY

In summarizing the most important of the numerous and conflicting vowel theories thus far propounded, we should perhaps best limit our consideration to those which have been adduced from some type of actual scientific proof, and at the same time, to those which have attained to some degree of acceptance.

That of Willis above quoted was the earliest of our really modern scientific theories evolved from and resting upon substantial experimental evidence. He concluded that a voiced vowel is made up of at least two tones: that produced by the vocal cavity or cavities, and that resulting from the vibration of the vocal cords. But he maintained at the same time that so far as pitch was concerned, the first was independent of the latter. In other words the glottal tone or fundamental might be inharmonic to the cavity tone. He talked usually of but one tone or pitch as characteristic of the vowel. He says where he describes an experiment using a funnel-like pipe plus a reed: [1]

"It has long been established . . . that any noise whatever, repeated in such rapid succession at equidistant intervals as to make its individual impulses insensible, will produce a musical note. For instance, let the musical note of the pipe be g^2 and that of the reed c^1, which is 256 beats a second, then their combined effect is g^2 . . . g^2 . . . g^2 . . . (256 in a second) in such rapid equidistant succession as to produce c^1, g^2, in this case producing the same effect as any other noise, so that we

[1] WILLIS, Wilfrid. On vowel sounds, and on reed-organ pipes. Trans. Camb. Phil. Soc. (1830) III 231.

might expect *a priori* that one idea suggested by this compound sound would be the musical note c^1.

Here as elsewhere, it is evident that Willis conceives of the voiced vowel tone escaping from the lips as consisting of a compound group. The tone of the vocal cords corresponds in his analogy to that of the reed (or his c^1 above) and that of his pipe to one of the vocal cavity (or the g_2 above). This is illustrative of the experiments he performed. He made use of a funnel shaped cavity to the bottom of which he could fit various sized reeds, and proved to his own satisfaction that he could thus obtain sounds resembling vowels by modifying the cavity. Where he made use of closed tubes

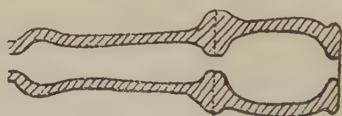


FIG. 11. Paget's Resonator for *o* (no) Resonances reversed. Pitches 912/456

of different lengths he maintained that sounds were produced by these which much resembled different vowels. He gives us an example in another passage.

"Experiment shows us that the series of effects produced are characterized and distinguished from each other by that quality we call the vowel, and it shows us more, it shows us not only that the *pitch of the sound produced is always that of the reed* or the primary impulse, but *that the vowel* produced *is always identical for the same value* of *S* (the length *of the pipe*). Thus in the example just adduced g^2 is peculair to the vowel ɔ (as in 'all'); when this is repeated 256 times in a second the pitch of the sound is c^1 and the vowel is ɔ: if by means of another reed applied to the same pipe it were repeated 171 times in a second, the pitch would be f°, but the vowel still ɔ. Hence it would appear that the ear in losing consciousness of the pitch of *S* (the length of the pipe) is yet able to identify it by this vowel quality. But this vowel quality may be detected to a certain degree in simple musical sounds; the high squeaking notes of the organ or

[1] Willis, *op. cit.* Italics mine.

violin speak plainly *i*, the deep bass notes, *u*, and in running rapidly backwards and forwards through the intermediate notes we seem to hear the series *u, o, a, e, i, i, e, a, o, u,* etc., so that it would appear as if *in simple sounds* that *each vowel* was *inseparable from a peculiar pitch* and that in the compound system of pulses, although its pitch be lost, its vowel quality is strengthened . . . "[1]

In other words, Willis conceived of each vowel as being "inseparable from a peculiar pitch" which in this case is traceable to "the length of the pipe." A little later, he explains the manner in which this cavity tone may be aroused, as follows: [1]

"According to Euler, if a single pulsation be excited at the bottom of a tube closed at one end, it will travel to the mouth

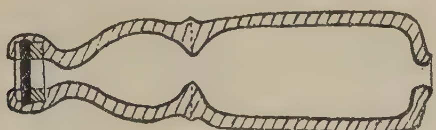


FIG. 12. Paget's Resonator for *u* (who) Pitches 608/362

of this tube with the velocity of sound. Here an echo of the pulsation will be formed which will run back again, be reflected from the bottom of the tube, and again present itself at the mouth where a new echo will be produced, and so on in succession till the motion is destroyed by friction and imperfect reflection . . .

"The effect therefore will be a propagation from the mouth of the tube of a succession of equidistant pulsations alternately condensed and rarified, at intervals corresponding to the time required for the pulse to travel down the tube and back again; that is to say, a short burst of the musical note corresponding to a stopped pipe of the length in question, will be produced."

This is a statement of the basic law involved in the "cavity tone theory" used to explain differences in vowel quality. Willis simplifies the explanation by comparing the "vowel tone" to that produced by an organ pipe. This pipe is perfectly regular and hence

[1] WILLIS, (as before) *Vowel Sounds etc.* Trans. Camb. Phil. Soc. 1830. III, p. 243.

its natural period is governed by the length. If it were irregular you would state it in terms of capacity or volume of air which it contains. This becomes necessary when we consider the very irregular mouth cavities. But Willis said right at the beginning, that he proposed "neglecting entirely the organs of speech, to determine, if possible, by experiments upon the usual acoustical instruments . . . what conditions are essential to the production of these sounds." This is probably the reason why he speaks of length alone, since his analogy is that of the organ pipe, and length is what is there involved.

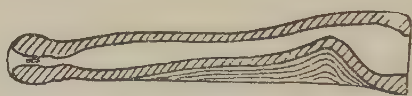


FIG. 13. Paget's Resonator for æ (hat) Pitches 1932/645

It is evident that he sees the cause of a vowel's quality in that one fixed pitch which corresponds to the natural period of a mouth cavity of one certain size. And he tries to make the point, that this pitch will remain constant regardless of any rise and fall in the glottal note. In other words these two tones need bear no mathematical relationship to each other. Hence his theory is not susceptible of a "harmonic" interpretation. This "harmonic" or "overtone" extension of Willis's "cavity tone" theory was later developed by Wheatstone. So far as Willis is concerned, any kind of stimulation of that cavity tone pitch recognizable in a given vowel, would stimulate its quality. So he says he hears "the high squeaking notes of the organ or violin speak plainly *i* the deep bass notes *u*," etc. And he goes even farther in this analogy, when he attempts to show that you may keep the glottal note constant and

change the vowel by altering the pitch of that one characteristic tone which would correspond to the natural period of the cavity. His analogy in this case brings into play a simple toothed wheel and a light spring whose length can be changed.

"Having shown the probability that a given vowel is merely the rapid repetition of its peculiar note, it should follow that if we can produce this rapid repetition in any other way, we may expect to hear vowels. Robinson and others had shown that a quill held against a toothed wheel would produce a musical note by the rapid equidistant repetition of the snaps of the quill upon the teeth. For the quill I substituted a piece of watch-spring pressed lightly against the teeth of the wheel, so that each snap became the musical note of the spring, the spring being at the

FIG. 14. Paget's Resonator for *i* (eat) Pitches 2579/322

same time grasped in a pair of pincers, so as to admit of any alteration in length of the vibrating portion. This system evidently produces a compound sound similar to that of the pipe and the reed, and an alteration in the length of the spring ought therefore to produce the same effect as that of the pipe. In effect the sound produced retains the same pitch as long as the wheel revolves uniformly but puts on in succession all the vowel qualities as the effective length of the spring is altered." [1]

In the first quotation above, his experiment was designed to show that he could change the glottal pitch at will, and yet maintain the same vowel merely by holding its cavity pitch constant. In this one, the process is reversed. And if the applicability of the experiments were accepted, both would have to be looked upon as opposing the "fixed pitch harmonic" theory, and so far as Willis's idea is concerned goes contrary even to the "relative pitch" theory. For it is evident that he sees an independent relationship between the two. Gen-

[1] op. cit.

erally speaking it may be said that Hermann held to the same view. However, he conceived of the vowel tone as being more complex,[1] even in its cavity tone elements. These elements Hermann grouped together under the term "the vowel formant" and the usage of that term has now become quite general.

This aspect of vowel theory, may be said to be still debatable. Scripture [2] espoused the Willis-Herman

FIG. 15. Another Paget Resonator for *i* (eat) "designed to increase the whistle action of the front cavity."

view, and extended it. Rayleigh concludes that both may be legitimate and not inconsistent: [3]

"When the relative pitch of the mouth tone is low, so that, for example, the partial of the larynx note most reinforced is the second or the third, the analysis by Fourier's[4] series is the proper treatment. But when the pitch of the mouth tone is

[1] HERMANN, *phonophotographische Untersuchungen* Pflüger's Archiv. f. d. ges Physiol. (1890) LXXIV 380 ff. (same) (1894) LVIII p. 270 and p. 51 (the same) vol. XLVII p. 359, 374.

Weitere Unterscuchungen ü. d. Wesen der Vocale, ibid. (1895) LXI p. 192.

HERMANN and Matthias (same) (1894) LVIII 258.

[2] SCRIPTURE, (op. cit.) Chap. XX and XXVIII, and Carnegie pub. No. 44, pp. 107 et. seq., etc.

[3] RAYLEIGH, Lord. Theory of Sound. London (1896) § 48, 66, 322k, 397.

[4] **The following references on the Fourier analysis may be of service to the reader who is interested:**

FOURIER, Théorie analytique de la chaleur, Paris (1822) Ch. III.

HERMANN, *Phonophotographische Untersuchungen* Pflüger's Archiv. (1890) XLVII p. 47 (and) *Die Bedeutung d. Fehlerrechnung bei d. harmon. Analyze von Kurven,* (same) LXXXVI 92 (also) *Kurvenanalyse u. Fehlerrechnung,* LXXXIX p. 600 (of same) (1902).

SCRIPTURE, E. W. Elements of Experimental Phonetics, Scribner's N. Y. (1904) p. 561 ff. and Chap. XXVIII.

PASCAL, Repertorio di matematiche superiori, Milano (1898).

MILLER, D. C. The Science of Musical Sounds, Macmillan, N. Y. (1922) p. 92 ff. Lecture IV for a complete treatment including modern equipment devised to carry out the process mechanically.

high, and each succession of vibrations occupies only a small fraction of the complete period, we may agree with Hermann that the resolution by Fourier's series is unnatural, and that we may do better to concentrate our attention upon the actual form of the curve by which the complete vibration is expressed."

Helmholtz[1] took the Wheatstone view[2] and has been followed by quite a number, including Bevier[3] and Miller.[4] Whereas, Auerbach, one of Helmholtz's

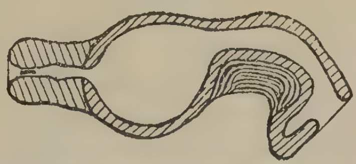


FIG. 16. Another Paget Resonator for *æ* (hat) Pitches presumably 1824/608

students and the foremost of the present German physicists who have engaged in vowel studies leaves the matter frankly undecided[5] just as Rayleigh[6] of the foremost of the British scientists, and most of the French did.

[1] HEMHOLTZ, (Ellis translation) Sensations of Tone. Longmans, Green, N. Y. (1912 ed.) p. 103 ff., etc.

[2] WHEATSTONE, Westminster Review (1837) p. 27.

[3] BEVIER, L. *Analysis of Vowels.* Physical Review (U. S.) v. 10, p. 193 (1900); v. 14. pp. 171, 214 (1902); v. 15, pp. 44, 271 (1902); v. 21, p. 80 (1905).

[4] MILLER, D. C. (as above).

[5] AUERBACH, F. in vol. II of Winklemann's Handbuch der Physik 2nd ed. (1909) p. 656 et. seq., etc.

[6] RAYLEIGH, Lord, Theory of Sound. London, 1896, p. 397.

CHAPTER III

WHEATSTONE'S CAVITY RESONANCE, HARMONIC, OR OVER-TONE THEORY

In that a harmonic relationship is seen as existing between the vocal cord tone, or if you will, the fundamental, and that tone which responds to the natural period of the buccal cavity above, there arises a necessity for distinguishing between this theory and that of Willis. Wheatstone stated it in one brief article contributed to the Westminster Review in 1837, found on page 27 of that volume.[1] It is given by way of commentary on Willis's earlier article,[2] and as a historical treatment of previous attempts to construct heads and machines which would artificially reproduce vowels and speech. It is now so difficult to get access to this article of Wheatstone's that it might be well to extract from it all that part which would seem to deal with his theory as to the cause of vowel quality. We may skip over his comment on machines, historical data, and the theory as Willis stated it; for his treatment of the latter is not at all argumentative—what he says is a mere summary of what Willis said. The latter was more explicit too, and went into detail. Willis also published cuts and careful analyses which are lacking in this article by Wheatstone, containing but three tables. One of these is on consonants and the other two are given herein. Wheatstone summarizes his conception as to the cause of vowel differences in the following words:

[1] WHEATSONE, CHAS., Westminster Review, Vol. 28, p. 27.
[2] WILLIS op. cit.

"The vowels are formed by the voice, modified, but not interrupted, by the varied positions of the tongue and lips. Their differences depend on the proportions between the aperture of the lips and the internal cavity of the mouth, which is altered by the different elevations of the tongue."

In another chapter we called attention to the fact that this much seems to have been more or less generally known since the days of the early Roman Empire, or even the earlier Greeks. Certainly it was quite clearly perceived by Kempelen,[2] and appears to have been recognized before him by the Abbé Mical, and perhaps Albert le Grand.

VOWELS

3. 05	G^2		4.7 C^2	Indefinite.
3.8	Eb^2	Aw	O	Oo
2.2	Db^2	Ah	Ou	
1.8	F^3			
1.0	D^4	Ae	Eù	
0.6	C^5	A	Eú	
0. 38	G^5	E	U	

"This table indicates all the most usually pronounced vowel sounds, but practised ears might distinguish others intermediate in each series; for each vowel may pass to the next in order, either above or below it, by imperceptible gradations. Each of these vowels may be long or short, according to the duration of its sound in a syllable."

Wheatstone continues the paragraph which we started above, as follows:

"The vowel sound *aw* as pronounced long in fall and short in folly, is formed by augmenting the internal cavity by the greatest possible depression of the tongue, and at the same time enlarging the separation of the lips. Departing from this sound

[1] Op. cit.

[2] Kempelen, W. Formation de la voix humaine.

there are two series, the one represented in the vertical row of the following table, the other in the horizontal row. In the first, the external aperture remains open, and the internal cavity gradually diminishes by the successive alterations of the tongue. In the second, the tongue remains depressed, but the aperture of the lips is gradually diminished. There is also an intermediate series of vowel sounds, obtained by different elevations of the tongue when the lips are partially closed; these, though abounding in many foreign languages, are not used in our own; they are shown in the second vertical column."

It will be observed that this scheme of Wheatstone's is primarily an acoustic one. To judge by the symbols he used, he must have had the triangle of Chladni,

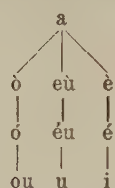


FIG. 17. Chladni's Triangle (1809)

or that of Du Bois Reymond in front of him:

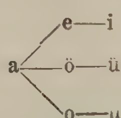


FIG. 18. Du Bois-Reymond's Triangle (1812). Indicates primarily jaw and lip opening.

Presumably his Ae is our phonetic ɛ; his A our *e*; his E our *i*; his Ou our *u*; and his Oo our *U* (in *foot*) or our ə in *the* or even our ʌ (in *cut*); the Aw is of course our ɔ ; and Ah our *a*. His other symbols would need no interpretation. He continues.

" . . . The extreme inadequacy of our written language in its representation of the articulations of speech is very obvious. We have six characters which are called vowels, each of which represents a *variety* of sounds quite distinct from each other,

[1] See Chap. 2.

and while each encroaches on the powers of the rest, many simple vowels are represented by combinations of two letters. On the other hand, some simple vowel letters represent true diphthongs, consisting of two distinct simple vowels pronounced in rapid succession; thus, a consists of a and e, i of ah and e, and u of e and u. Again, the literal diphthongs are mostly simple vowel sounds, as ea in bleak, ie in thief, &c.

"This want of correspondence between the characters of our written, and the sounds of our spoken language, has been a great obstacle to the proper understanding of the real elements of speech. A child is taught that the letters W, H, Y, make the syllable *why;* now if we examine the sound of this word we shall find it to be formed by the rapid succession of the vowel sounds U, ah, E. In attempting, therefore, to imitate by artificial means the sound of this word, we should pay no regard to the letters of which it is formed; the elementary *sounds* alone are the objects of our attention. The same observation is generally applicable to the words of our language."

In that, there is nothing which concerns us particularly in our consideration of vowel theories. It does, however, explain the symbols he has been using, and makes it evident that he has nothing under consideration but the pure vowel. It might be well now to continue with enough of his discussion of Willis, to show the basic interpretation of that phase of the theory as Wheatstone conceived it. For in a part of Wheatstone's theory, he agrees with Willis, and takes that over. That part of his interpretation can well be represented in what immediately follows the above:

"Turn we now to the recent and interesting researches of Mr. Willis on the vowel sounds. His first object was to verify De Kempelen's observations. Having obtained the vowel sounds, U, O, A" (Wheatstone's Ah, or our *a* ?) "very distinctly, he found that on using a shallower cavity than De Kempelen had employed and sliding a flat board on the top of the funnel, that he could obtain the entire series in the order U, O, A, E, I."

This qualification as above given by Wheatstone is probably induced, because of the difficulty which

Kempelen frankly states he had in reproducing the vowels we represent phonetically as *e* and *i*. On the preceding page, Wheatstone comments on the results of Kempelen as follows:

"(p. 31) De Kempelen found that by placing a conical tube like the bell of a clarionet, before the reed he employed, different vowels were obtained according as the bell was more or less covered. On such a tube, U is heard when the tube is nearly closed, O when it is about half closed, and A when it is entirely open. It is only when a rapid transition is made from one of these sounds to another that each can be distinctly recognized; when the cover is kept upon the tube for some time in the same position, the *sound appears always to be A.*[1]"

This is all he says of Kempelen's vowels. It will be noted that *e* and *i* are not included. I have also italicized the last part, which, if we may be permitted to disgress, is of great interest to us, especially since it occurs in Wheatstone's comment. Is that true in normal speech? If not, does it throw any light on the question as to how good the mechanical reproduction made by Kempelen actually was when divorced from the guessing factor of the ear's interpretation? Or if on the other hand it is true in human speech, does the fact throw any light on the stability of the vowel *a* in linguistic change? He says:

"De Kempelen infers from this that the sounds of speech become distinct only from the contrast which exists between them, and that they obtain their perfect clearness only when connected in entire words and phrases."

Herein we have commented on the same conclusion which has been reached from our observation of facts more or less the exact contrary. For we have noted that it takes an appreciable time for any vowel to develop its pattern. Hence the longer you hold it (within certain limits) the clearer it should become. And

[1] Italics mine.

if its duration is materially reduced, so that its pattern does not have time to develop its characteristic shape and make all of its partials perceived, any vowel will be deadened. The English ear at least then seems to hear for any back vowel and most of the front ones, be they what they may, an ə; or tends to interpret the *i* as *I*; this being true more particularly when they occur on low pitches.

After that digression we may return to that part of the Willis theory which Wheatstone seems to accept, and use as a part of his own.

"(p. 33) Let the line a b c d represent the length of the pipe measured from a, and take a b, b c, c d, &c. respectively, equal to the length of the stopped pipe in unison with the reed employed; that is, equal to half the length of the sonorous wave occasioned by the reed.

No. I.

IE A O U UOAEI IE A O U

•a •b •c •d

No. II.

IE A O U UOAEI IE A O U UOAEI IE A O U

•a •b •c •d •e •

No. III.

IE A O U

•a U •b O A EI •c

"The lines in these diagrams must be considered as measuring rods placed at the side of the tube, with their extremity *a* opposite to the point at which the reed is placed; the letters and other marks show the effects produced when the open extremity of the pipe reaches the points so marked, and the distance, therefore, from these points to *a* respectively is the length of the pipe producing the effects in question.

"Now if the pipe be drawn out gradually, the tone of the reed retaining its pitch, first puts on in succession the vowel qualities I E A O U; on approaching c the same series makes its appearance in inverse order as represented in the diagram,

then in direct order again, and so on in cycles, each cycle being merely the repetition of b d, but the vowels becoming less distinct in each successive cycle. The distance of any given vowel from its respective centre points is invariably the same in all.

"If another reed be tried which gives a higher sound, and whose wave, represented by the second figure, is consequently shorter the centres of the cycles a, c, e, &c. will be at the distance of the sonorous wave of the new reed from each other, but the vowel distances, and this is an important point to be remarked, will be exactly the same as before."

It is evident that down to this point, Wheatstone has agreed in every respect with Willis. We pause to comment here, since the last quotation indicates that in his mind, as in that of Willis, each vowel has a quality which may be reproduced by stimulating the natural period of one long pipe considered as a whole. In other words the natural period of the buccal cavity is considered as producing one characteristic note, due to its function as a whole. And the quality of the vowel is ascribed to the pitch change of this one note. He proceeds:

"It may be stated as a general rule, that if a certain length added to the reed gives to its sound a determinate vowel character, the same vowel is heard when the same length is added to, or subtracted from, a length equal to any simpl multiple of the original wave. (2na+v).

"When the pitch of the reed is high some of the vowels become impossible. For instance, let half the wave of the reed (Fig. 3) be less than the length producing U. In this case it is found that the series never ascends higher than O; and that on passing C, O the reverse series commences. In like manner, if reeds of higher notes be taken, more vowels are cut off. This is exactly, Mr. Willis remarks, the case in the human voice. Female singers are unable to pronounce U and O on the higher notes of their voice; for example, the proper length of the pipe for O is that which corresponds to the note C on the third space in the treble, and beyond this note in singing it becomes impossible to pronounce a distinct O . . .

"Mr. Willis further states that cylinders of the same length give the same vowel, whatever be their diameter or figure; and

that so far as he has tried, he has always found that any two cavities yielding the identical note when applied to the embouchure of an organ pipe, will impart the same vowel quality to a given reed, or indeed to any reed, provided its note be flatter than that of the cavity."

Of course when he rules out diameter as an influencing factor here, he is speaking of the regular shaped "cylinders" rather than the irregular formation of the

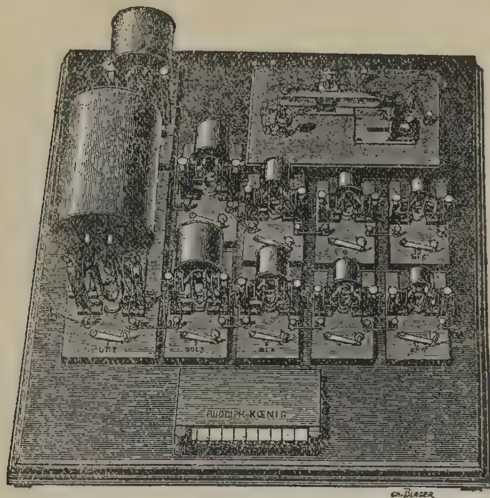


FIG. 19. For synthetic reproduction of vowel quality thru compounding of up to ten different partials which an analysis shows to be present in the sound as heard.

vocal cavities. We may consider this qualification to have been made, when he speaks of "any two cavities yielding the identical note." The paragraph now to be given contains the crux of this quotation from Willis. It is particularly interesting to observe that in Wheatstone's mind, he apparently saw no conflict between Willis's theory and that he proceeds to propound. We might even go farther and say that to all appearances Wheatstone feels he is merely clarifying

and elaborating the theory as Willis proposed it. Yet generally speaking, we have talked of the two as being in conflict with each other. And regardless of how it appealed to Wheatstone, it would appear that they are.

"Mr. Willis finally concludes, from his experiments, that the vowel quality, added to any sound, is merely the co-existence of its peculiar note with that sound; this accompanying note being excited by the successive reflections of the original wave of the reed at the extremities of the added tube.

"This view of the matter naturally associates the phenomena of vowel sounds with those of multiple resonance, a subject first investigated by Professor Wheatstone."

In what now follows, there is a development of this idea of resonance applied to the vowel. This contribution to vowel theory is strictly his, and he should be given full credit for it. German scholars are accustomed to refer to it as the Helmholtz theory. Our own generally follow their lead, and likewise so refer to it, either in slavish imitation, or as a result of ignorance. It can hardly be said which viewpoint would be the most charitable to assume. It would appear to be time this error were corrected. In speaking of the "resonance theory" it should be designated as "Wheatstone's theory." When we talk of the "cavity tone theory" there is no doubt in the author's mind that it should be referred to as the "Willis theory." The ideas of Kratzenstein the Russian, Kempelen the Viennese, l'abbé Mical the Frenchman, and the host of others who preceded them, were too nebulous to be considered as having crystallized in the form of a theory. Willis stated the law, performed the experiments, and applied the mathematical formulae. And even after the whole century which has elapsed since he did so, we still disagree and hence cannot say without dispute whether he was in error or not when he attributed the vowel quality to the tones which characterized the

cavities, and that, independent of the glottal tone (or fundamental). In a continuation of the above citation, Wheatstone states his extension as follows:

"The phenomena of simple or unisonant resonance are so well known that we need only call attention to one or two of the most

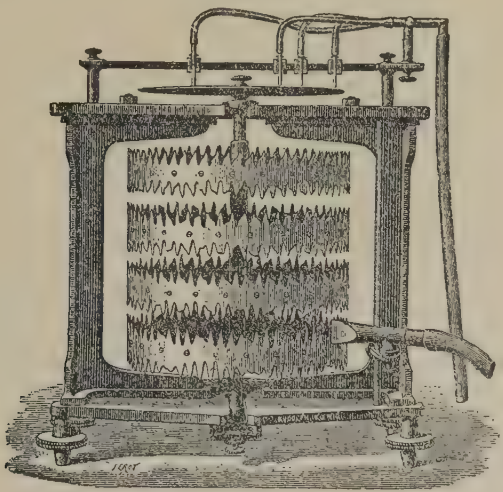


FIG. 20
The Koenig-Rousselot Vowel Siren

For transposing into sound the vowel wave as it is recorded and then cut out in metal. Stimulated as in a siren, by blowing an air current against the sharp edges. This is a purely synthetic process which it would appear should give a splendid reproduction of the original providing nothing had entered into the result to falsify it. But the author's impression was of a much more imperfect imitation than Sir Richard Paget obtains by means of a double cardboard resonator.

striking facts. If a vibrating body be brought near a column or volume of air, which would be capable of producing the same sound were it immediately caused to sound as an organ pipe or otherwise, then the sound of the vibrating body is greatly reinforced, as when an harmonica glass is brought before an unisonant cavity, or when a tuning fork is placed at the embouchure of a flute, the apertures of which are stopped, so that if blown into, the flute would sound the same note; in the

latter case the experiment is more remarkable, as the sound of the tuning fork is scarcely itself audible. The same effect takes place when the cavity of the mouth is adjusted so as to be in unison with the tuning fork.

This latter experiment is also usually erroneously credited to Helmholtz. It is curious to note how even in science we like to have our mythical heroes, to whom we ascribe a whole succession of accomplishments which belong to others. Now and then, it is true, a scientist is found who recognizes the fact that the Hollander, Donders, performed this experiment before Helmholtz made use of it. Wheatstone continues his statement of theory as follows:

"We now come to the new facts of resonance: a column of air will not only enter into vibration, when it is capable of producing the same sound as the vibrating body which causes the resonance, but also, when the number of vibrations which it is capable of making is any simple multiple of that of the original sounding body, or in other words, if the sound to which the tube is fitted is any harmonic of the original sound.

"For instance, if a tube closed at one end by a movable piston is taken, and its length adjusted to six inches, it will resound as an unison to a C tuning fork; and if we shorten the length of the tube to three inches, the unison will no longer be reciprocated, but its octave will be heard. The same effect is produced by altering the cavity of the mouth.

Here then is a statement of the fundamental theory upon which is based his conception of the cause of vowel quality. Or in other words, here is a statement of the "harmonic cavity tone or overtone theory" which we so often use in the present day to explain vowel quality. That makes, of course, no distinction between the "fixed pitch" and relative pitch" theories. On its face, his conception would seem to involve the first rather than the latter, as an explanation of vowel quality differences. Helmholtz did likewise until the vigorous attack of the Swede v.Qvanten, and then he

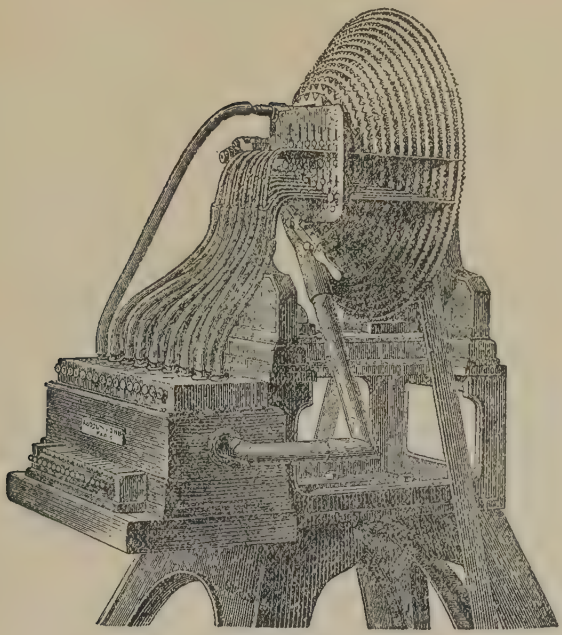


FIG. 21
Koenig Vowel Siren

It provides for synthetic reproduction of vowel quality by fusing the pure tones of those partials which show as being present in a mathematical Fourier analysis of the vowel curve. Since provision was made for varying loudness of the individual components and the tone produced for each element would be very much purer than that created by organ pipes and could include very high pitches, such a synthetic reproduction should make it possible to give a very faithful representation of the original vowel sound, regardless of which one that might be, in either the "front" or "back" series. But while the author was privileged to make numerous attempts, he has had to acknowledge inferior results to those obtained by Sir Richard Paget with simple two tone resonators. It may be seriously questioned whether anyone has thus far obtained isolated artificial vowels which are in any sense perfect enough to be unrecognizable from the human vowels produced side by side with it. Even Stewart's electrical analogue using tones about as pure as modern equipment can produce, and reconstructing the vowel concomitant which created about as distortionless a curve as it is possible to record, may hardly be said to have done that. Yet until that has been successfully done, the author cannot help but feel justified in saying that no vowel theory has been proved to be all sufficient. (See J. Q. Stewart's report, Nature, July 8, 1922, No. 2757, Vol. 110, p. 311.)

turned to the latter which seems to have been the theory held by Donders the Hollander and Pipping the Finn. Now follows in Wheatstone, an interesting description of the effects accomplished with a Jew's-harp. His references to its tongue will of course not be confused with the human tongue, but to avoid this possibility the author has deemed it wise to insert in brackets after the word "tongue": [of the Jew's-harp], in order to aid the reading.

"By placing before the mouth a vibrating lamina, which produces a lower sound than can be obtained from a tuning fork, the tongue of a Jew's harp, for instance, and successively adjusting the column of air so as to be one-half, one-fourth, one-fifth, &c. of the column reciprocating the fundamental sound, the octave, twelfth, double octave, seventeenth, &c. will be produced. The relative numbers, considering the vibrations of the tongue" (of the Jew's harp) "as unity, are 1, 2, 3, 4, 5, &c. The mouth produces precisely the same effect as this changeable tube does, and all the beautiful sounds which Mr. Eulenstein manages with so much skill are produced by this means; they are multiple resonances of the column of air, and not the vibrations of the tongue "(of the Jew's harp)" itself, as was formerly supposed.

Now of course, an inescapable question will no doubt arise in the reader's mind, as it does in the author's. When we place the Jew's-harp to the teeth and start its tongue vibrating, the actuator is located at the opposite end of the cavity series from where it is placed when the vocal cords so function. But if the cavities are so stimulated and such a stimulation is what causes the vowel, is it not pertinent to ask why such a Jew's-harp does not produce as perfect a vowel as the vocal cords do? As you twang the reed of that Jew's-harp and adjust your cavities for the vowel *i* do you hear an indistinguishably human *i*? An unfavorable answer must inevitably militate against the unequivocal acceptance of the cavity tone theory as an

all sufficient explanation of vowel quality. But apparently Wheatstone does not so recognize it. He proceeds:

"Similar results are obtained when the vibrating tongue of an Aeolina is brought before a tube, and its length is altered; and this case resembles Mr. Willis's arrangement. The same multiple resonances are produced also when the cavity of the mouth is substituted for the tube. In these cases the fundamental

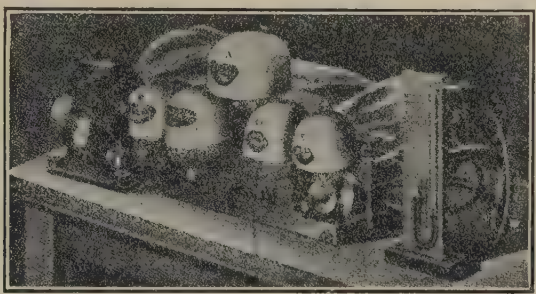


FIG. 22. A typical example of the auto-suggestion so often indulged in by those who construct artificial vowel machines. Would the listener recognize the vowel involved here, if the letter and lip position were not visible; or if the vowel were not coupled with some consonant or in a word such as "mama"; or if the operator did not prepare him ahead of time by leading him to compare one of a group with another; or did not otherwise place him in a prepared state of mind, or "set" for what was intended to be reproduced?

sound is louder than when the tongue of the Jew's harp was employed. The sound of the larynx itself may be substituted for that of the vibrating tongue, and similar harmonic sounds will be heard; this experiment may easily be made by placing a piston tube before the mouth, while the voice continues to sound rather a low note. About two years ago a young man named Richmond exhibited a novel kind of musical performance with the voice: on examining the circumstances under which the sounds were produced, it was ascertained that the continued sound or drone was produced by the larynx, and that he had acquired the art of adjusting the cavity of the mouth so as to

fit it for resounding to any multiple. In this way he was able to command these subordinate sounds in any succession, and even to dwell upon them; and he could perform a great number of airs.

Wheatstone's reference to "resounding to any multiple" when compared with the expression "multiple resonances" makes it clear that in his use of the latter term he is talking of the "overtones." "Multiple resonances" therefore, do not merely mean the resonances of several cavities. What he is developing here, is the "overtone" or the "harmonic" theory, and the term "multiple" is synonymous with what we might designate as "exact multiples of the fundamental."

"Some kinds of sounds are better suited to produce these multiple resonances than others, and it is an universal fact, that wherever these subordinate sounds can be distinguished, there also the vowel qualities are heard; and reciprocally, when a sound puts on successively different vowel qualities, these multiple resonances are audible. The tongue of a Jew's-harp, which so readily gives rise to these subordinate sounds, is obedient not only to the vowel sounds, but to almost all the articulations of speech. The free reed or Aeolina tongue, when it is such as can enter readily into vibration, is affected in a similar manner; but when it is too rigid, though it may produce as clear a musical sound as before, the multiple resonances and vowel qualities are equally lost, not perhaps because they do not exist, but because they are overpowered by the original sound of the reed.

"We do not mean to assert that each multiple resonance is a distinct vowel sound. But we infer, that when a tube is added to a reed or vibrating tongue, whatever may be its length, a quality is added to the original sound, which depends on the feeble vibrations of the air in the added tube: these increase in number in proportion to the shortness of the tube; and when the number of vibrations thus excited is any multiple of the original vibrations of the reed, the energy of the resonance is so greatly augmented as to produce the effect of a superadded musical sound.

"Thus it is evident that the vowel qualities and multiple resonances are different forms of the same phenomena."

With the above citation we have completed the inclusion herein, of all Wheatstone said in regard to vowel quality and the cause of differences between different vowels. It will be observed that he said very little in regard to physiological function. He was satisfied with the work Willis did, and the artificial results he (Wheatstone) obtained with a duplicate of Kempelen's machine, which by the way may still be seen and tested at King's College, London. If he conceived of this apparatus as satisfactorily proving his theory, it is evident that he thought of the mouth cavity functioning as one simple resonator. Yet he spoke constantly of "multiple resonances" and used the plural. So there must have been some idea in his mind implying an involvement of more than one partial. In any event, we would apparently be justified in concluding that Wheatstone clearly postulated the "overtone" or "harmonic cavity tone" theory, and is entitled to that credit which is so often given to Helmholtz.

CHAPTER IV

PREVIOUS X-RAY VOWEL EXPERIMENTS

TECHNIQUE.

Very few X-ray studies have been made of what the vocal cavities are doing in the course of vowel and speech production. This is probably due in a large measure to the danger involved, more particularly where a large number of exposures must be made of the same subject, and taken at the same sitting. Unfortunately, the X-ray burn never gives any warning that it is occurring, until several days after the damage has been wrought. And very little can be done to check its progress, which under such circumstances continues to spread farther and farther. One of the foremost radiologists of Europe who was using tongue movement in his attempt to devise moving-picture X-rays, burned his face so badly that new skin with openings for the eyes and mouth, and a new nose and ear had to be surgically provided. He cautioned the author very earnestly, and yet with all that it fell to the latter's lot, to lose his whiskers on one side (though after about a year they came back) and to pass through several week's resulting pain and burning. This of course would not occur, if no more exposures at a sitting were called for than X-ray operators currently permit themselves for any one subject. But where we desire to make comparisons between a group of vowels, we must make the exposures from the same subject kept in the same position and with all other influencing factors maintained just as constant as possible.

The excessive expense has also no doubt been largely responsible. If one had to pay the current commercial rate of $5 and $10 apiece for each picture not many such studies would be made. Even where the co-operation of some laboratory can be had, the expense is no small item; and it is not an easy matter to stimulate enough interest among professionals to bring about

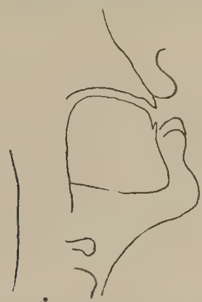


FIG. 23. Traced as best the author could from Barth-Grunmach German Subject. Note the distended throat cavity and tongue arching back to the K position, not against the alveolar ridge up towards the teeth, as the tongue-arching vowel triangle would have it.

such a gratuitous offer from them. Hence we need not be surprised to observe that three of the four studies of importance which have been published, are by medical doctors and X-ray specialists. Barth,[1] and Scheier [3] are the only two who went so far as to have plates made of even one complete set of tongue-posi-

[1] BARTH, E. and GRUNMACH, E. *Röntgenographische Beiträge zur Stimmphysiologie.* Vowels: I, E, A, O, U; Dipthong Oa, Ae, Ue, Oe. Arch. f. Laryngologie, Bd. 19, Heft 3 (1907) pp. 396-405 Barth; pp. 405-407 Grunmach.

[3] SCHEIER, M. *Die Bedeutung des Rötgenverfahrens f. d. Physiologie der Stimme und Sprache,*

Arch. f. Laryngologie, Bd. 22, Heft 2, p. 175 (1909).

German vowels: A, O, U, O, Ue, E, U, J, Ae, Oe, On.

Consonants: M, L.

3 of larynx in relation to buccal cavity.

3 of larynx alone.

Several tracings and drawings.

tion negatives. And of course, not much reliable information can be gained from one lone set of vowels produced by one individual. The cost of the plates alone, however, very shortly runs up into hundreds of dollars. The author has spent something over $3,000 on the X-rays for the present study, and was granted an additional $500 by the graduate research council

e

FIG. 24. German Subject, by Barth-Grunmach. The front buccal cavity is probably as closed as for *i* (ee) in Fig. 23, but the throat shows more difference, since the lower edge of the back throat line slopes in closer to the pharyngeal wall. We have noted the same fact in the X-rays of the present study. This movement may be due to relaxation in muscular tissue thus damping the high partials more and resulting in a "mellower" tone; or it may come solely from a movement in the epiglottis due to interior larynx function pointed out in Figs. 37 to 48.

of Ohio State University from which some copper halftones herein were made. He also had the free use of the X-ray laboratories in its medical school, voluntary offer of the services of Dr. Hugh Means and his operator; and unstinted cooperation from the whole photographic school under Prof. Haskett, on the final, or "check-up" aspect of these experiments. Without that, the expense would have been very considerably greater, as may well be imagined, since something over

400 subjects were used before we came to that final check.

And regardless of expense, such check-ups have to be made. It does not suffice, to draw conclusions from the one negative in which something unusual appears. Neither are we justified in holding a traditional theory to be confirmed, merely because it appears to be, in

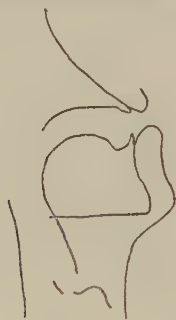
ue

FIG. 25. (Our *y* or German ü ?). As in the others above and following the palate line cannot be followed in the original; but since it is possible to take an orientation for each one from the bony alignment which is usually more or less constant in position on the negative in spite of the radical up-tipping of the jaw and varying curve in the spinal column, the same palatal line may serve for all vowels in their respective tracings. This has been done.

the negative of one set. An illustration of this fact shows in Fig. 139, where the tongue position for the vowel *a* is relatively flat, as the triangle theory would have led us to expect it to be. But such positions as shown in Fig. 138 from the same subject, or 109 and 110, or 155, or 181, or 193, give us an idea as to how misleading our conclusion would have been. In such a study we are constantly making discoveries of this kind. So the expense of our work mounts ever higher and higher, as we proceed. This expense is one of the

reasons Meyer[1] gave for turning to his "plastographic" method in preference to the X-ray.

The reader will no doubt have available the few published comments on technique which may be found in the works of previous authors. These will be especially in the works of Scheier[2] and Eijkman.[3] The author has profited not only by what appears in these



oe

FIG. 26. (Our ϕ ?). It is of interest to note that the front buccal cavity manifests a position which is very much more open than that evident for *e* in Fig. 24. The vowel triangle, and practice among language teachers, have postulated the same tongue position with the difference traced only to lip position. But the lip position is not radically different here either.

[1] MEYER, E. A. (first X-ray photographs of vowel position, in) Medizinisch-pädagogischen Monatschrift, f. d. gesamte Sprachheilkunde, Jahrg. 17, Heft 8, 9, in (1907) but reported in a paper, presumably in Stockholm or Upsala Sweden, where he is a professor at the university, in (1905).

Ibid. Schwedischen Phonetik (tracings) Vox 1916 H. 1.

Ibid. 2 photographs and 1 set of tracings for N. German vowels *u, y, i, o, ,e a* published in Festschrift Wilhelm Viëtor, Marburg (1910).

[2] SCHEIER, M. *Die Anwendung der Röntgenstrahlen f. d. Physiologie d. Stimme u. Sprache.* (No x-ray photographs or tracings).

Deutsche med. Wochenschr. (1897) No. 25. See also Archiv f. Laryng. Vols. VI and VII.

[3] EIJKMAN, L. P. H. *Tongue Position in the Pronunciation of Some Vowels. By Roentgen-Photographs.* (No photographs. A number of tracings —mostly conventionalized composites.)

Vox. June, 1914, Heft 3.

articles, but from personal help and the experience of many who have not published. For as is well known, numerous such studies have been begun and been given up, in consequence especially, of the above mentioned danger and inconvenience, or the expense. Many of these go back to a rather early date. So for example, the author knows that in this country, both

ae

FIG. 27. (Our ϵ or German ä ?). Traced from the X-rays of the vowel produced by a German subject, as published by Barth and Grunmach.

Professors Grandgent and Weeks made such early beginnings, which were given up because of the danger involved. The latter undertook his not long after the discovery of the X-ray in 1895. The former whose first studies on Vowel Measurements appeared in 1890 and 1892, began a continuation of them in X-ray studies not long after, which he also gave up for similar reasons. Such were also, Rousselot, Marage, Calzia, Gutzmann, Dessauer, Stephen Jones (in the University of London Phonetics laboratory, two or three of whose photographs appear to have been published by Noël-Armfield) et. al. There is also a very extensive literature available to us all, which covers both X-ray and photographic technique. To this the

author evidently need not refer, either in detail or in biblography, since both are so extensive and easily traceable in their own bibliographies. But it has been deemed wise to give here the salient features of the methods in the present study.

There are two different processes which have been used to obtain X-rays of the interior mouth cavities.

ɑ

FIG. 28. Tracing from the X-rays of a German subject by Barth and Grunmach. Reduced from theirs by ½. The amount of their reduction was not indicated, but appears to have been about ½. Note that the tongue is flat an ddoes not arch up against the velum as on the vowel triangle. See Fig. 67.

In the first attempts, a marker was always used to outline the tongue position. Some kind of chain was commonly used for that purpose. Both Weeks and Grandgent made use of the same in their attempts begun not long after the discovery of the X-ray. Until recent times, the X-ray was very slow in its operation, and the vowel had to be repeated over and over again, sometimes for several minutes. Barth's negatives were obtained in this way. The reader will bear in mind the fact that the tongue is a soft surface within the hard walled cavities provided by the jaws and front palatal arch. These hard surfaces tend to wipe

out all vestige of tongue outline, for they present a relatively impenetrable surface to the X-ray. What shows on the negative is therefore blank wherever such hard surfaces occur. The lead chain was a metal, denser than these bones. Where the exposure was prolonged for a sufficient time, it appeared therefore, as a somewhat vaguer line. The use of a marker in early

a

FIG. 29. German Subject. Published by Barth and Grunmach. Note the tongue constriction of the throat in the neighborhood of the epiglottis down in the throat. Herein we have noted this narrowing at that point to be a characteristic for the *a* (ah) series of vowels. For that reason we have expressed a preference for the older vowel triangle scheme of a century ago, the *a* (ah) at that side the *i* (ee) at the top for the palate, and the *u* (oo) at the front for the lips.

experiments was primarily for that purpose. For experiments published by Barth and Grunmach [1] a plain chain was used. These appeared in 1907. Meyer [2] had been at work as early as 1905, using small lead plates strung on a string, which therefore form essentially a chain. He also attached such lead plates to the roof of the mouth. It so happened that these two independent groups working without knowledge of each other, both published their results in 1907, and the marker was utilized in both cases.

[1] See our Note 1 on page 45. [2] See Note 1, page 48.

Scheier hit upon the idea of utilizing an old man with no teeth.[3] By this means he was able to get the best photographs thus far published. The roof of the mouth, and the line of the velum cannot be followed in his cuts. The lips are also sometimes missing. It would therefore not be possible to make measurements of cavities since we are dependent too much on our

o

FIG. 30. German Subject's vowel, as obtained by Barth and Grunmach. Note that the closure is again against the throat wall instead of up against the velum as in the tongue-arching vowel triangle.

imagination. Yet to judge by the half tones his negatives must have been splendid. It can only be regretted that he failed to trace the lines which must have shown on the film. This could have been done with a pencil before the plates were made, and the data thus preserved for all future investigators. It is always a matter of regret that such facts should be lost with the negatives which of course are very perishable and only available to a few. Mere admiration of technique does not compensate us for the loss of detail which takes place in the making up of such cuts. In his study of Scheier's negatives, this regret grew so strong in the author's mind, that he redoubled his

efforts to preserve every detail in his own negatives for the reader of the present study. To this end, he dedicated months of work to delineation just for the one selected group of plates in these studies. He anticipates some criticism on this score but hopes that in the end his judgment will be vindicated.

It is also to Scheier that we owe what appear to be

oa

FIG. 31. Is this our ə (uh) our ɔ (aw) or some other vowel? How much more sensible it would be for all scientists engaged in a study of speech to utilize the same symbols as the chemists and others do. There is surely wisdom in adopting the one now generally recognized alphabet, that of the International Phonetic Assn.) Note that the narrowing is again against the throat wall instead of the velum, but is distended more than in Fig. 55 for *a*.

the first published articles showing the value of the X-ray for phonetic research. At that time, he made use of the fluoroscopic screen. He has been in the vanguard when it came to calling the attention of the phonetic world to X-ray improvements which could be advantageously used.

For many years chemicals have been used to intensify the X-ray outline of soft surfaces. Such use is common among doctors where X-ray photographs are made of the stomach and digestive tract. Sub-

nitrate of bismuth is most commonly utilized for such purposes.

Eijkman [5] coated the tongue in that manner in order to accentuate its outline. In its essentials this process is in one way much like that of Barth [1] and Meyer,[2] for it places a foreign body on the tongue. So far as objections to be urged against the final result are concerned, it will, however, fall in the same category as those of Scheier.[3] Eijkman also leaves us dependent upon tracings [5] in so far as his tongue-position studies are concerned. He gave us some very fine cuts, however, in his study of the larynx and lower vocal cavities.[6] Nevertheless these do not go much above the lower curve of the jaw bone. At this point, any such chemical coating is superfluous, as Scheier's remarkably fine photographs a, b, c, Tafel IX show.[3]

In the work of the group at the Hamburg phonetic laboratory, Gutzmann and Calzia [8] leaned towards the no-marker technique used by Scheier. Stephen Jones in the phonetics laboratory at London made use of chains. He also passed one through the nostril and down over the soft palate in order more clearly to show its movements. But as his colleague Daniel Jones said, nobody but he could submit to such a process. Then too it will be noted from the experiments published

[1], [2], [3], [5]. See notes pages 45 and 48 herein.

[6] EIJKMAN, L. P. H. *Radiographie des Kehlkopfes.* (No vowel tongue positions. Some good negatives of larynx and jaw bone curve.)

Fortschritte auf dem Gebiete der Röntgenstrahlen Band VII, Heft 4 and 6 (1904).

[7] GUTZMANN, (see comment in) Phys. d. Stimme u. Sp. p. 141 (1909).

[8] CALZIA, PANCONCELLI — G. Die phonischen Bewegungen des Menschen im Röntgenbild (Hamburg, 1914). No photographs. (Elsewhere in his Bibliographia Phonetica, in Vox, he has made further comment on Meyer, etc.)

In Vox and elsewhere here and there, are found a few other tracings. HOFFMAN, Vox 1916 H. 3, etc.

NAVARRO-TOMÁS, Tomás, *Siete vocales* españolas, in Revista de Filología Española, 1916, III.

herein, where both the upper and lower line of the Velum shows without the use of such a marker, that a chain over the top of the Velum would give no reliable record as to the position and shape of the under side. One of the reasons lies in the power many subjects have of raising and lowering the Uvula independent of movements made by muscles of the Velum itself. Another is manifest in the varying thicknesses of the Soft Palate.

A very few of these experiments were published by Noel Armfield, following the war. But nobody seems to have carried them out much farther. However these, along with those published by Meyer and others perhaps, seemed to have influenced the International Phonetic Association (in which Daniel Jones of the London laboratories holds such an important position) to at least modify somewhat the pernicious physiological vowel triangle. For now the front vowel line is made to drop straight down from the center of the Palate instead of slope back and down from the Alveolar Ridge.

In this country as in Europe, numerous other attempts have been made to utilize the X-ray for an examination of Vowel positions and theories. In some cases these have resulted in such serious injury that they had to be abandoned. In others, no successful technique was developed. And in a few perhaps, the results which were obtained ran so violently contrary to our general conceptions, and vowel theories as a whole, that the authors either could get nothing out of them, or thought best not to make them public.

CHAPTER V

THE SECRET OF SUCCESSFUL SPEECH X-RAYS

Anybody realizes that the thing which makes a photographer is his dexterity and judgment. Even an amateur who has engaged in some developing will understand this fact. But the same thing may be said of the exposure in portrait photography. It is the trained judgment acquired from years of practice which makes the good photographer. You may state certain formulas, provide a mechanical tank development, lay down a few set rules, and otherwise reduce the work to a routine, but that does not necessarily mean success. For that reason, it becomes a very difficult task to give any adequate description of what should be done in taking speech X-rays. Any photographic manual or photographer can explain for us, the simple basic photographic processes. Any X-ray operator can demonstrate in a few minutes, the essential things which one need know in order to make an exposure. The mechanics of the task are not difficult.

But, the ordinary X-ray exposure will not suffice. That goes without saying. Perhaps this is one of the reasons why the X-ray study of the vowel has received such scant attention. Once the X-ray exposure itself is made, the task has just begun. Even after the negative has been carried thru an ordinary development, it may be said to be totally unserviceable for purposes of such a study as the present one.

The reason for this latter fact is evident without calling attention to it. We have but a passing interest in the bony surfaces represented by the jaw, segments

of the spinal column, and the cranium. But we must be able to see the fine lines of the soft surfaces within those bony cavities. It is those soft muscular surfaces which change the aspects of articulation. It is they which alter the size and shape of the cavities. And what we are interested in, is in knowing exactly what those soft-walled cavities look like. We want to be able to make exact measurements of their dimensions. Hence it is absolutely essential that we see the line of the velum, and be able to trace the exact mid-dorsal line of the tongue, and that of the palate which is above it; and that we know the position of the epiglottis, and clearly distinguish the back wall of the pharynx. So long as these are distinguishable, it makes no difference to us whether the X-ray positive shows the bony surfaces as black as coal. Most X-rays are made for entirely different purposes. Fine detail in bony surfaces is usually a mark of a good negative. Hence most operators would condemn very roundly any such negative as we require. On the other hand the average X-ray negative of the head, even though most doctors would consider it a splendid piece of work, could be of but little service to us.

A long and painstaking re-development process must be resorted to, in order to bring out fine soft-surface lines which ordinarily are lost.

Herein lies the secret of success. The process is a very complex one, since it involves a very careful control over not only the numerous development processes the technical X-ray operator knows nothing about, but a precise and mathematical placement of the subject, target, and film, and a graduation of current and time of exposure which is intimately dependent on the balance maintained between these factors.

For that reason we shall treat them separately, and in detail in the chapters which follow.

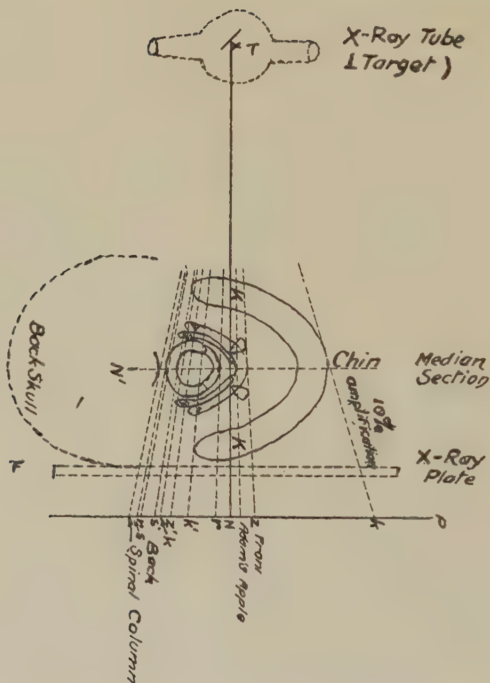


FIG. 32. Placement of Subject, Negative, and Target. Showing how the median line with its indication of cavity dimension which we seek, may vary radically in its amplification unless careful mathematical computations are each time made in advance, all because the diameter of heads vary. This has been previously done for all our X-rays and thus the amplification is kept constant at 10% for each of those published herein.

CHAPTER VI

DELINEATION OF THE CAVITY AT POINT OF WIDEST OPENING

In our laboratory we have used both the marker and non-marker methods in obtaining X-ray experiments. We have also tested the various objections which have been raised against each one. For after all it is quite unscientific to fall back on a guess that such and such a process might vitiate results. Neither does it suffice to quote somebody else's opinion to the effect that this might be true. The scientific way is to perform such experiments as will demonstrate conclusively whether or not the guess is true.

So far as we can ascertain, each method has its advantages, and most of the objections urged against previous experimenters are not substantiated by experiment. Such at least may be said of those advanced against Meyer's marker, if we might judge by the experiment we devised for the most vital one; namely that which urged that the use of those very light little plaques on a thread, would operate to modify or falsify the vowel the subject was supposed to produce. It was said that the weight would so press down as to cause the subject to alter the tongue position necessary for the production of the vowel in question. Of course we are only concerned as to whether this modification would be sufficient to produce a perceptible difference in the vowel's quality.

Very much heavier chains were used, and the subject's pronunciation recorded. Then the chain was removed and another record made. These records were then played, while several groups of thirty ex-

aminers with and without trained ears, were set to tabulating: 1st. Which vowels had normal quality and which did not; and 2nd, which might have been produced by a subject having such a chain in his mouth extending well down into the Esophagus. No difference between those with and without chains was discovered. And as a matter of fact it does not stand to reason that the weight itself would exercise any appreciable effect. If the reader will place his index finger on his tongue while he says "ah" (*a*) and attempt to hold it there while he says "ee" (*i*), he will note the really surprising force which the muscles of the tongue can exercise in opposing his pressure.

So we had to conclude that this was a foolish objection to the use of a marker. However this does not offset the effect of gagging referred to farther on.

The recording of the sound produced in the course of the X-ray exposure, serves as a constant check on any such possibility of having "snapped" a tongue-position which was not characteristic of the vowel it was supposed to represent. And in other ways, such a control must be considered essential. Hence in all the author's experiments except for some of the check-ups in which this was not so vital, a record was made either by telegraphone or phonograph at the same time the exposure was taken. Since this machine was syncronized so as to record nothing except the vowel being pronounced at the time of exposure, a careful control was had giving us an assurance as to exactly what was produced. And if any vitiation of quality was manifest the negative was immediately discarded.

The use of a marker to delineate surfaces which otherwise would not show, is of course no longer necessary as it was in the early X-rays. Within recent times X-ray technique has made such rapid strides towards perfection as to eliminate this necessity in a

vowel study. This is especially true since the advent of the Coolidge Tube, the various French intensifying screens, and other such improvements. The exposure time may now be cut down to an extremely small fraction of a second, at least where such a technique is used as that of Drs. Commandon and Lomon. By this means, the vowel position may be caught at any stage of its production. Much sharper outlines also result. Nevertheless with all this, it still remains nearly impossible to obtain the tongue outline at those places where hard surfaces like the jaw bone impede. If no marker is used, a certain amount of guessing must usually be resorted to for studies of that neighborhood.

Yet the subject is more at ease where you can bring him in and seat him for the experiment which proceeds without ever looking into his mouth. Some people are so "finicky" that the mere touching of their chin to open their mouth precipitates regurgitation. There are others who cannot even swallow noodles, macaroni, and like stringy foods without cutting them into small bits. In case an absolute necessity is felt for using such individuals as subjects, the operator is constrained to take his exposures without markers or other aids.

There is one serious objection to be urged against experiments obtained in this manner. An examination of such experiments as those shown[1] in Figs 101-121; and 139-141, for example, will show that the median or center line of the tongue may in some places differ considerably from that produced by the edges of the tongue. This difference varies radically not only

[1] Author's Speech and Voice.—Macmillan.

[1] Compare X-rays in the author's Speech and Voice — Macmillan, Figs. 168, 180, 181, 193, 224, 225, 109, 110, 129, 138, 139, 140, and 141.

from vowel to vowel, but also from subject to subject for the same vowel.

In the beginning the author, like Calzia and others, accepted Scheier's view that the tongue median would manifest itself in the line of greatest darkness. It was only by accident that he discovered in the course of experiment, that this was not necessarily true. This observation was brought about by the experiment shown in Fig. 138, of the author's Speech and Voice. It just happened that a marker was used on this subject in order to carry conviction to him personally as to certain facts we were studying. And it came as a distinct surprise when the author noted incidentally that the line we had taken to be the median was very much closer to the pharynx than that delineated by the marker. There were four distinct lines here: one for each edge of the tongue, another we had taken to be the center, and that indicated by the marker. So far as this study was concerned this discovery showing that the non-marker technique was misleading meant that a great deal of money had been wasted and all the time thus far devoted spent in vain. The reason will be evident to one who gives the matter even cursory consideration, viz:

The true diameter of the vocal cavity, is shown by the exact median line of the tongue, and not that represented in the edges, or any line between the two. The capacity of the cavity is indicated by the diameter. The raising of the tongue edges may be of considerable importance, and it is well that we see the line for both the edges and the center. But if we jumped at the conclusion that the line shown by the edges represented the center, it is evident that any study we based thereon would be more or less worthless.

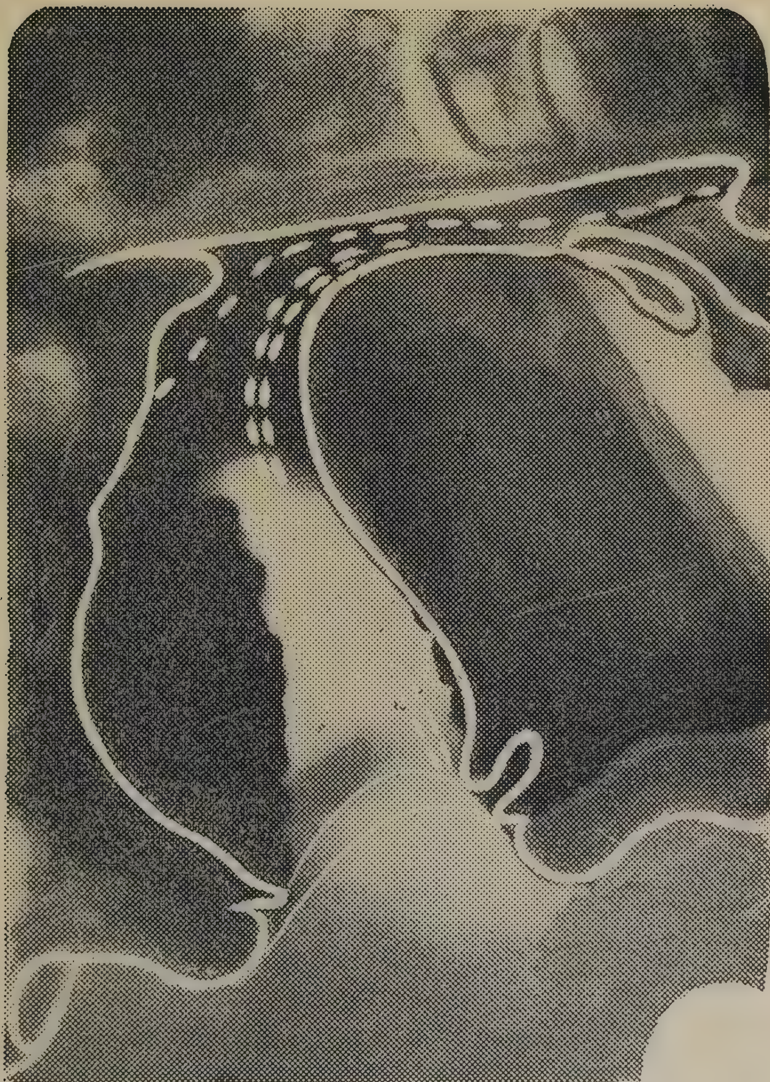


FIG. 33. A life size, or perhaps we had better say, an unreduced X-ray cut.

Though not so evident as in the X-ray referred to in the next paragraph this discrepancy between the line formed by the edges and that of the center can be appreciated by an examination of Fig. 33. The edges are shown by the broken line and the center by the heavy white line. It will be seen that in this case we would estimate the size of the cavity as much smaller than it is, if we had no marker to delineate the median line and were thus forced to judge by the edges. Thus serious misconceptions might result.

Or we might take Fig. 138 of the Author's "Speech and Voice" (Macmillan) where as in Fig. 33 here, the median delineated by the marker shows clearly in the long white line. What is between the two is extremely black. Now the transfer from the negative has practically wiped out an extremely fine shaded line which (if we followed Scheier or Calzia) would ordinarily be taken to represent the center mass of the *genioglossus* or tongue. It follows generally about half way between the two. This would correspond just about to an extension upwards of the fuzzy-edged black line pointing straight down from the crotch of the epiglottis, in Fig. 138. It is also vaguely shaded off like this one which might make our guess as to its exact boundary vary as much as half of its distance from the edges.

This vagueness of line is another serious objection to using it under any circumstances to represent the median upon which cavity computations are based. It is evident that such a blending of that shaded line is inevitable, since the fibers of the *genioglossus* so radiate in yucca plant fashion as to form no distinct line of demarcation. On the other hand it is perfectly possible for the more sharply bounded fibers of some

of the other muscles such as the *styloglossus* to throw a shadow in some places which may be misleading.

Now if we had failed to use a marker (as Scheier, Calzia, and others recommend, and we started out to do) and taken one of these shadowy lines to represent the median, we might have been led to the conclusion that the harsh quality heard in the "pinched tone" *a* of Fig. 138[1] was due to a constricted passage between the tongue and velum. We might even have concluded that the "tongue got back into the throat too much," as Miss Hoffman seems to have done.[2] That is what has so often been said. But with the marker present, we see at once that the statement is here untrue. The back cavity[1] is much greater for this *a* in Fig. 138, than for either 139, 140, or 141. The raising of the tongue edges occurs only in the back for Fig. 138, mostly at the top for Fig. 139, and throughout the whole extent of the tongue for both 140, and 141. So also it will be evident that we might *never know when the tongue were convex and when concave* without a marker. For the subject often so tips his head as to make the two edges of the tongue almost exactly coincide.

These are serious objections to be urged against experiments made without any marker used to delineate the exact center line of the tongue. For all phonetic purposes we must have that line. We cannot make any authentic cavity computations without it. So while it might be said that the time has passed when we actually must have the marker in the sense it was first used as a delineator, it still proves to be almost essential for our purposes. However adequate precautions must be taken to keep it in the exact center. Scheier

[1] See author's Speech and Voice.—Macmillan.
[2] Vox. 1916, Heft 3, p. 140, et. seq. with tracings from X-rays.

called attention to such a failure on the part of Barth in the first of his experiments shown on Tafel 16 for *Ae* (presumably meant for the vowel we would record phonetically as ɛ). Where the marker goes no farther down than the epiglottal crotch, the tendency is for the tongue to push it off on to one side. Hence in this exposure of Barth's it shows as having slid clear up on the edge of the tongue.

The author has taken two means of preventing such an occurrence. In the first place he used a marker long enough so that it could be swallowed and go well down into the esophagus. By keeping hold of the other end and centering this directly under the tip of the nose, a pull would thus be exerted from either extreme which would force the center on to the line desired. In order to bring this about, the subject was asked to swallow and pull simultaneously on the exterior end just before each new exposure was made. We had difficulty getting some subjects to relax the marker after each pull, and the taut line is therefore observable in some of the author's negatives in Speech and Voice, such as subject No. 236's, Fig. 101, 105, 107, 112, etc. But this was not considered of great importance since the point where the edges of the tongue tend to curl up, and where there was most opacity of bony structure, was along the back hump of the tongue, caused by the lower jaw and parts of the cranium.

A second precaution was taken to be sure the marker was kept along the median line at that back point. The subject was asked to open his mouth and an examination with the author's laryngo-periskop was made after such exposure. In the later series this proved superfluous.

Since, to obtain the exact size of the cavity in median

section, it proved to be absolutely necessary to use a marker of some kind, an exasperating series of experiments had to be gone thru with in order to discover one that would work.

Meyer's little plaques strung on a string were first tried. But along with all other types of lead markers these finally had to be discarded. For some reason or other, which is even now not clear, they made some subjects violently ill. Was this due to the influence of the X-ray on the lead and a possible chemical reaction whose poisons were carried into the stomach?

Gold chains were then tried. But gold is not so opaque to the X-ray as is lead. So those a millimeter, and a millimeter and a half, had to be resorted to in order to obtain the necessary detail in the negative without increasing the length of exposure unduly.

But the Link Chain Gags the Subject.

The links pinch and tickle and lead to a most unfortunate distortion of the cavity and tongue positions. The moment the subject starts such a process we might just as well give up.

For that reason, the smallest of locket chains obtainable from a jeweler proved to be unusable. And something had to be done to avoid the effects which inevitably followed the working of those links within each other and the tickling contact they made.

Mineral compounds such as barium, were of course out of the question. They would accentuate the edges of the tongue as much as the center. Hence they would give an entirely distorted idea as to the size of the cavity along the median line. It would be far better to take the exposure without any coating.

Some of the best of the X-rays in our group were obtained by means of a marker using extremely thin

strips of gold foil. To make these, long narrow 1-2 mm wide strips of gold beater's foil were floated over a fine silk thread laid along the surface of a ribbon of warm gelatin. The thread gives it tensile strength. And the gelatine sufficient body when it is cold, to hold it until swallowed, then it melts and leaves the metallic foil sticking to the tongue. And this marker really cannot be felt. Nor is the swallowing a more disturbing process than if it were a noodle. But a great deal of dexterity is needed in its making. New ones have to be provided in rather too rapid succession. And exasperating delays result.

The author was more fortunate in his other marker. He succeeded in finding a Lausanne Swiss jeweler who was very painstaking and careful in his work though he charged an atrocious price. He made him a very thin thread like metallic rope marker about 1/2 mm. in diameter. It is of lead alloy, and so because of its density it registers very clearly in the X-ray negative. Even its twists will be clearly seen in the half-tone. The voice vibrations make it appear larger than it actually is sometimes, but a fair idea of its negligible diameter can be noted where it is taut. He plated this marker with gold, which seemed to eliminate any trace of the above mentioned illness. It was very flexible like a thread, and is made somewhat flat, so it will lie prone and not creep. It is also fine enough so that the capillary attraction holds it to a given position along the tongue. The swallowing process is about the only one which will dislodge it. And this will tend to pull it farther and farther down, so the subject needs to keep hold of one end with his thumb and finger. For this purpose, a commercial clasp large enough to be unmistakably felt, is provided at the end.

Finally, this marker has an added advantage over

any other we have used. It can be readily sterilized and used over and over again. And too, its opacity made possible a very considerable reduction of exposure time, which is no small item.

Thus all the objectionable features were eliminated. Once it is swallowed, this marker can hardly be felt, and the subject is shortly so unconscious of its presence that its removal brings a distinct surprise. I say it can hardly be felt, but of course that statement postulates the elimination of the psychological or imagination factor. And the operator must acquire a "bag of tricks" in order to side-step these. As stated before, some people are so "finicky" that it is actually impossible to open their mouths without disturbing them. Any marker is, of course, hopeless with such as these. Then one likes to elaborate on his experience, and he spreads the word among his friends. In that event a later subject's imagination sometimes runs riot. So such possibilities must be provided against it in advance.

Ascertaining the Median along the roof of the mouth is, of course, quite as important as it is to be sure of its position along the tongue. This is more forcibly impressed on us now than ever, since we have repeated evidence in these experiments that a change in the movement of the tongue, for example, may be compensated for by another in the lips, velum, epiglottis, or other moveable part. Also, that the velum, or more particularly the enmeshing cavities formed by constricted and relaxed positions of the *glossopalatine* and *pharyngopalatine* arches, may conceivably function to alter not only the vowel, but tonal quality or so-called "placement" of the voice. We seem to to have proof of radical difference of movement in this velum and other such surfaces, not only from vowel

to vowel, but from subject to subject. It is therefore not justifiable to postulate a constant position for the velum, as some have done who have published so-called mouth mappings, theoretical tongue positions, or even X-ray experiments and tracings therefrom.

Figs. 160 and 161 in the author's Speech and Voice will show that without that inferior velum line, we might get an entirely distorted idea, not only as to apertures (which might be so vital), but as to size and shape of cavities. Such Figs. as 193 and 194 would indicate that you cannot depend on the superior line marked by the velum, to tell you anything on which you might rely to judge what was happening to the inferior or mouth slope of the velum. In other words, the velum, including the two arches, is constantly changing its perpendicular as well as horizontal shape, and thickness, as well as position, in the passage from vowel to vowel, and that even in the same subject. A marker line which comes in over the top of the velum would fail, therefore, to give any reliable idea as to the velum line underneath. Hence we conclude that such a nasal chain as that used by Stephen Jones might well lead to unreliable estimates of the buccal cavities involved. How are we to know its position then?

This velum and the arches attached to it on either side, which for the sake of simplification, we have been considering as a part of it, exert pulls on the surface lining which radiate in several directions. This fact coupled with the glandular secretion, causes the best hospital adhesive tape (even that used on suppurating wounds) to release its attachment very quickly where we attempt to use it as a means of fastening lead strips to the velum for the purpose of defining it. You may dry up those secretions for the time being by making use of atropin. That, however, makes the

mouth so dry as to seriously incommode the subject.

The author finally devised a process for so marking the median line of the velum, but found there was no material deviation as between this and the unmarked line. This of course disregards the uvula. Such a marker was regularly used on a subject for either the first or the last experiment. This served as a check and, if any deviation was found, it was used on all vowels.

In the experiments herein it will be noted that such a marker was also used to delineate that line along the hard palate which would correspond to the mid-dorsal position immediately under it.

It will be remembered that the uvula has its muscle, which is capable of pulling it up or letting it down. This tendency is quite manifest in some subjects, and not so much in others. Subject No. 347 showed a very decided tendency towards such a pulling up, particularly on the front vowels, as will be seen by a comparison of Figs. 153 and 154 with 155, 156, and 157 (in Speech and Voice). No marker can be devised to indicate this change. But a technique of development has finally been worked out which makes a marker for either the velum or uvula unnecessary. Since the latter hangs from the roof in median position, one needs but follow the uvula line to that of the velum in order to be sure as to the position of the median line along the roof of the mouth. And as will be noted, the line of both uvula and velum is quite clear in the X-ray experiments published herein.

CHAPTER VII

THE EXPOSURE — PLACING THE SUBJECT

To obtain the exposure, the subject is seated with the side of his face towards the target, and the other cheek resting flush against the film and intensifying screen. In most of his experiments the author used his special screen made by M. Gaiffe, Paris. It will be noted that the subject is thus placed between the screen and the X-ray tube (which fact needs, of course, no explanation except for the benefit of those not conversant with the ordinary procedure used). In some experiments, however, such as those made with a moving picture technique, the target was placed behind the screen, the subject in front, and the camera in front of the whole.

The first type of placement is indicated in Fig. 32.

It will be noted that the customarily cited target distance, current, and exposure time is not given herein. That is because of the fact that these vary from subject to subject — an inevitable consequence of the technique used.

That statement of course needs some modification. It will be evident to even a casual reader, that a precise location of the target in relationship to subject and film is of more importance in such a vowel investigation, than it is to the average X-ray operator. Our experiment is for the purpose of ascertaining the exact dimensions of the vocal cavities in speech. And precise measurements are necessary. If such placement care is not exercised, our whole experiment is invalidated. Perhaps we may explain.

Faces of subjects differ considerably in width. In order to reduce the exposure time just as much as possible, we work with the target set as close to the head as is feasible. Hence a very slight variation in cross-section diameter of heads would result in material differences of magnification of the mid-dorsal or sagittal X-ray silhouette. This would, of course, produce such a distortion of apparent cavity sizes as to make our experiments worthless, unless that varieation were exactly measurable. And even if that were possible, the necessity for making more or less elaborate corrective computations before we could make comparisons between experiments, would seriously vitiate their value.

Study Fig. 32.

In order to avoid this, and keep the same constant for all experiments, in that they may be strictly comparable at a glance, it becomes necessary to change the target distance with every subject. The reader will see the reason. The X-rays shoot out from the center of the target on oblique lines towards the plate. The subject is placed between the two, with his head resting against the latter. The mid-dorsal line in his head therefore is equivalent to some such object as a ruler placed with its flat side between the plate and the target.

In order to correspond to that median line, the ruler would rest with its sharp edge right against the tip of the nose. For the reader's benefit, a ruler for making comparisons has been engraved with Fig. 110. The original had to be eliminated in the cut to save space. It gave 3 white marks for 2 cm. By laying a regular millimeter scale alongside this we could then check the amounts of amplification present in the negatives for each subject, we knew that our previous computations

had resulted therefore in this mid-dorsal line being magnified in the X-ray exposure by 1/10th. If we had moved that ruler closer to the traget, the magnification would have been greater.

The principle here is the same as that involved in the shadow cast by any object placed between a candle and the wall: the closer the object is moved to the candle, the greater you magnify the shadow on the wall. Here the line involved is that at the tip of the nose. As heads vary in their diameters, this line will shift in its relationship to target and plate. The case above mentioned where we moved the ruler closer to the target and increased the magnification has its counterpart in varying head diameters. For this is essentially what would happen where we used a subject like No. 207, whose head is materially wider in cross-section than is that of this subject No. 236. On the other hand, if we laid the ruler flush up against the plate, and thus moved it in the opposite direction — away from the target — the magnification would be nil. But we cannot get the plate up against that mid-dorsal line of the head, which is on a plane with the tip of a man's nose.

If we could move the target far enough away, we could reduce the magnification distortion. But, of course, such a movement of the target would inject the most objectionable feature possible into our experiments. For the farther away you move your target, the greater you must increase the time of exposure. And a reduction in time of exposure to the absolute possible minimum is the first *sine qua non* and the most important rule we need lay down for our guidance in such experiments as these.

An exposure which is extended beyond 1 second is seriously objectionable where we seek to catch a rec-

ord of the vowel in normal speech production. And where it can be cut down to 17 exposures per second, as was done in some of the moving picture experiments carried out in the course of this investigation, the resultant is nearer what the eye would see if it could observe the movement. For films projected on the moving picture screen are run at 16 per second.

It would be a splendid thing if the exposure time could be cut to less than 1/100th of a second, for then we approximate the sound-pattern time period for vowels. But for the present that is impossible. And if we could do it, it is very doubtful whether much use of that ability would be made. We have long been able to take extremely rapid moving pictures showing lip movement, but how many such studies have been made? The author has never published one such film he made in a comparative study of English and Spanish during the year 1923, run at an exposure rate of 1/72 of a second. He could not discover that there were enough facts shown which would not appear in an ordinary run, to justify such publication. The same fact would probably be true of X-ray moving pictures taken at a rapid rate.

Yet it would be a splendid thing if we could make exposures fast enough to show what the tongue is doing in the whole course of transition from sound to sound — i.e., from vowel to vowel, and from all of the numerous consonants to each of those vowels and to each other. The author has already begun such a study and hopes in due time to make the whole public. These must be taken rapidly enough to show where the tongue is: at the beginning of the sound, when it has reached its maximum, and when it stops. Some of those containing the first and last are included herein.

The greatest possible reduction in the time of exposure is the first principle we lay down for our guidance in these experiments. As a second one, we specify the obtaining of as much detail in soft surface lines of the interior mouth, as possible. We want to eliminate as much fuzziness in them as we can. The farther they are away from the film, the less pronounced will be the sharpness — that is, the more a vagueness and blurring of line will be manifest. This is one of the reasons why the film should rest flush against the face. The other reason will be understood by anyone who has attempted a time exposure with a camera. For in his most rigid position the individual is not able to hold any part of his body still enough to prevent blurred images. So distance and speed must both be reduced as much as is in any way possible.

If it were not for this necessity of keeping the subject's face flush against the film we might conclude that the easiest way of keeping this magnification factor constant, would be so to place all subjects that the tip of each one's nose would be centered at a given point between the film and target. But even if it were not for the above mentioned facts, such a proposal would probably have to be rejected. And that would be true if only because of the difficulty of keeping a steady position. For the head of the individual needs something to steady it and keep it from moving from right to left, which would not only make the lines fuzzy, but vary the amplification from moment to moment. Head rests of the type the old photographers used to employ would of course prevent this, but that would not overcome the two objections mentioned above. This eliminates the possibility of our employing variation in more than one of the factors mentioned. We have referred to three: the film, the

subject, and the target. And we have shown that adjustment by variation in location of the first two is out of the question.

We are therefore left with the necessity of shifting the target every time we employ a different individual for a subject. This is the only means by which we can keep the amplification of the mid-dorsal position constant for all subjects. This forces the operator to make a careful mathematical computation every time he places a new subject, in order that the target may be moved just far enough away, or closer up, so as to bring about a given amplification for all. That is to say, it devolves upon the experimenter so to adjust the target that the amplification of the speaker's vocal cavity in sagittal or rather median section along the mid-dorsal line will always give a constant. By so doing, we avoid prohibitive corrective calculations in the cuts after the experiments are printed. For these would otherwise be necessary in order to make comparisons and draw justifiable conclusions.

This previous adjustment of target has been regularly carried through for the series of experiments reported on in the present study. The subject has always been placed with his face flush up against the film. And since it is to our advantage to stay well within the field of the direct rays the attempt has been made so to locate the target in relationship to the subject's head, as to throw these rays against that part of the back pharyngeal cavity which is shielded by the curve of the jaw bone. This is the spot which gives us most trouble. This is true not only of the line manifest in the elusive mid-dorsal and curved-up edges of the tongue, but of the velum, and pharynx walls. That is the place where most of the interference from hard bony surfaces occurs.

Care has also been taken so to locate the target and turn the subject's head as to direct those rays on a line which would be exactly at right angles to our sagittal section profile. The reason will be evident, since otherwise distortion within the cavity itself would result. This would be much analogous to that observable if the image between the wall and a candle were turned more or less sidewise in relationship to the two. The same thing might be said of any perpendicular slant of the target. In so far as the subject's head is concerned, a slight deviation will be noted in the relationship between the levels of the jaw bones on either side. Determined efforts were made to control this factor, with such success as may easily be seen and appreciated. But since the rays are focused on the mid-dorsal line of the tongue, which is but a short distance from the palate, only a very slight median distortion could in any event occur. And any necessary correction would seem to have been provided in the use of the same hard palate line for all films of the same subject. There are so many details of this kind for the operator to keep ever uppermost in mind, that one must be constantly on the lookout.

Not only has the target been so adjusted for all exposures as to keep a 1/10th amplification constant for the mid-dorsal profile, but reduction of the negatives in their transfer to plate has also been controlled. As will be noted, a millimeter scale has been photographed directly on each one. The reader may therefore make the check for himself.

It thus becomes possible to compare the cavities of one subject with those of another without the need of mathematical computations. Where it is desired to compare the results obtained by other investigators, who have so published their experiments as to make

possible the computation of their cavities in natural sizes, those given herewith will have to be reduced by 1/10th after the figure in which they are shown is enlarged by the amount indicated. This should preferably be done by making use of the millimeter scale photographed on the plate. In order to facilitate such a study it would no doubt be wisest to first amplify those shown herein until the millimeter scale photographed on the plate shows 90 mm. for each 100 of the scale.

In comparing the cavity of one subject herein with that of another, or any two cavities for the same subject, no reduction for the amplification constant is really necessary. But since we are working in tenths (now that all the adjustment was made in the exposure phase of the study), it becomes a simple matter, and but a bit of rapid mental arithmetic for the reader to deduct 1/10th of whatever his figure may be, in order to ascertain the exact size of the original. When working on the physics aspects of vowel studies, such computations may conceivably be necessary. This may especially be true where we attempt a reconstruction of the cavity, for artificial reproduction of vowels. And also for use in comparing its tone with Fourier analyses and other such vowel studies.

The necessity of adjusting the target distance for every change of subject complicates our exposure and development technique. The instant you change the target distance a modification of the exposure process is required. And under that term, "exposure," we include length of time and current. This follows, since the farther away the target is placed the greater the exposure will be which is necessary to make the same impression on the plate. Such a variation in target distance would not make so much difference in an ordi-

nary X-ray negative. Neither would it for us if we were not dependent on very delicate adjustments in order to catch the outline of the velum and other soft surfaces lying within — and photographically impeded by — the hard bony surfaces of the mandibles, maxillae, and cranium.

If cognizance is not taken of this fact these soft surface outlines are often lost. Herein may lie one of the secrets of success. For if not heeded, and those lines are lost, especially on a subject who cannot be obtained later, the whole series of experiments is wasted. That is, for our purposes they are useless, because it becomes absolutely necessary to know the position of those soft surfaces in order to compute or even compare cavities.

It is essential, therefore, so to expose and develop as to bring out these soft surfaces. A careful adjustment of target distance, current, exposure time, and development is required in order that this may be done.

This fine balance of numerous variable factors is worrisome and disconcerting, but cannot be avoided. And since there are so many possible variations the author is unable to give cut and dried rules. One must rely upon his judgment and experience. And of course the former can only come as a result of the latter. The need for such an adjustment grows out of the requirements in the particular type of experiment with which we have to deal. It is unfortunate that we cannot reduce them to a rule or routine process, for that forces us to do most of our own work, since we cannot fall back on the experience of the technically trained X-ray operator.

CHAPTER VIII

THE REAL SECRET — IN THE DEVELOPMENT

The equipment of the modern hospital or clinical X-ray laboratory is admirably adapted for the type of negatives needed by the physician and surgeon. As was indicated above he seeks to record diseased conditions of bodily organs and detail in the bony surfaces, most of which is absolutely unnecessary for our purposes; and we need mathematical precision in certain fine lines within bony cavities which would be quite as useless to him. For us, the bony surfaces may be as black as coal on any print we take therefrom, and it still serves admirably so long as it shows those soft surface lines.

These soft surface lines we can only obtain by painstaking work with the negative. We must spend days over just one of these. For the doctor such delay merely to obtain finer soft surface delineation would only be detrimental. He must know right now what is to be known. In cases of pain and suffering and lurking death it is essential that no delay result. Then too, such a laboratory deals with masses of negatives. So these are the needs which are arranged for.

As nearly as possible, all processes are reduced to a formula. Everything goes off like clock work, it is so perfectly timed. Regular tank development is provided, and hence for the most part this aspect of the work is reduced to mechanical timing. Extreme care must of course be taken, but on the whole the mechanical way of doing the work doubles the assurance that it will be done without slips, most of which would consist

in spoiling the negative. Then too, it is evident that in the mass of work which has to be run off there is not time for hours, and days, and weeks of individual attention which is necessary to give negatives of the type we must needs have for these experiments.

. . . . .

There is not much which we can put down on paper to serve as a guide in the dark room process. That is

FIG. 34. (From Gray's Anatomy). The most important exterior muscles involved in alterations of vowel quality.

there is no more than will be found in any ordinary photographic manual. And none of that will serve as a substitute for experience and judgment. The author had to learn that fact in years spent as a rectigraph operator. He knows of no short cut. There are a few points which might be mentioned, as applying particularly to the type of negative with which our experiments have to deal. Soft tissue areas which lie immediately behind the curve of the jaw bone, and which are represented in the velum and other soft surface lines in that neighborhood, will present the typical manifes-

tations of an underexposed negative. And they will have to be treated as such. This treatment will therefore begin the moment the film is immersed in the developer. One must have learned to recognize that stage of development in a negative where all surfaces — the high-lights and shadows — have reached their maximum of *equalized* intensity. Professor Frank Haskett is accustomed to stress very picturesquely a certain fact which will bear repeating here. Says he: "When the uninitiated finds an underexposed film passing through his tray of developer, the common tendency is to overdevelop. This only accentuates the fault. The underexposed parts have received but a certain amount of light. The developer will precipitate evenly over all surfaces alike, whether underexposed or not, down to a certain point. When that undeveloped area has reached its maximum it cannot be helped any, by proceeding with the development, but the other surfaces continue their progress. Hence it may be said that to carry the development beyond that point can only lead to a wiping out of distinctions between such areas."

In other words, it is precisely the fine lines we seek which are by overdevelopment deliberately wiped out. And in the X-ray, overdevelopment is in the main regularly called for. So when the regular procedure is followed we lose exactly what we need, instead of obtaining it.

But our negative is also overexposed in parts. We said above that it was underexposed in the neighborhood of the upper pharyngeal cavity. In making the decision as to our rate of exposure, we therefore adjust for that area and correct for the others later.

The thing which disturbs us in the opacity of the dense jaw, preventing a record of the lines we need in

the soft surfaced velum and others like it. Since we must work to overcome the obstruction there presented, we must inevitably overexpose: for the softer surfaces in the pharynx immediately below the bow of the jaw; for the lips; for the epiglottis; and for the thyroid and cricoid cartileges, the latter two of which form the image for the larynx.

In regular development the operator can be guided by the appearance of neither the one nor the other. It is far and away more important to watch for the point of maximum development in the underexposed areas. The development should not be permitted to go beyond that. Yet on the other hand, if the development is not brought up to that point of maximum deposit for the underexposed surfaces, the negative will be so weak that no intensification will remedy it. That means that as a rule the surfaces manifest in the larynx, lips, and such like, will come out of the hypo so black as to be all but opaque even against a strong light. A print would therefore show absolutely white at these points, and it would make little difference how long you exposed it.

Hence, it may be said that even after the negative is submitted to the experimenter, developed, fixed, and dried — ready for careful examination under a strong light (or rather over a reflected light through a ground glass or over a white background) the work of preparation has but begun. These discrepancies must be equalized. Even that which is not apparent under such an examination may oftimes still be brought out.

In practice, the author has found it an almost impossible task to intensify one part of a negative without touching another. That is particularly true of negatives of this type, where the part to be intensified

is in the center . For that reason he usually proceeds to a reduction of the overexposed surfaces first.

There is great danger here in staining the negative irremediably. At this point there is every danger of so spoiling one negative as to lose a whole set and days of previous labor which went with it. Here again, nothing in the way of cut-and-dried formulas and instructions can be added to those found in any good photographic manual.

Since our negative, however, must of necessity be so badly overexposed in those areas we are to treat, a very powerful reducer becomes necessary. In general it may be said that one which works too slowly is more likely to stain than the more rapid one. The author found a permanganate reducer almost out of the question. He finally came to use his own radical modification of the one known as "Farmer's" formula.

It had to be renewed with the immersion of each new negative, and since that was done drop by drop, until the desired speed was acquired, it will be evident that this cannot be stated in terms of ounces or cc. We started it with a strengtth approximately 100 times that ordinarily used.

The negative was first thoroughly soaked in cold water, and if it had not already been passed through a hardening solution, it was so treated. Since we must handle it with warm fingers for so long, the coldest running water or ice, if in the summer, was kept constantly at hand, in order that the fingers and negative might be kept as cold as possible. If this is not done, we are almost sure to be suddenly shocked by finding the whole emulsion has slipped off of one of our precious negatives, thus again running the danger by such a slip, of spoiling a full set because of destroying one of the links in our chain.

Most manuals advise the use of a wad of cotton or a camel hair brush for reduction over isolated areas. Since our negatives are in part so strongly over-exposed, and the reduction must be carried on so rapidly for such a length of time, the author found this inadvisable. It almost invariably resulted in the creation of false shadows and lines which might easily be mistaken thereafter, for some of the surfaces pertaining to the negative.

This, coupled with the almost invariable stain, is what made it absolutely impossible to submit such negatives to even the best commerical photographer for reduction. They usually ascribed the stain to a failure to wash out the hypo. And it is true that great care must have been taken both in leaving the negative in the fixing bath long enough, and in washing sufficiently; otherwise the reduction is sure to turn out disastrously. But no commercial photographer ever returned to the author even the best of his negatives in a condition of proper reduction needed. So he has had to do all this work personally. It means slow, painstaking, and typically experimental attention. If the commercial man were willing to give the days and days of observant attention required, it would probably prove to be too expensive for such research purposes as ours. For there is not a negative presented herein, on which the author has not spent at least a day of such work alone.

Because of this tendency to streak, it was found best to plunge the negative right into the bath. That means of course, just the part to be reduced. In order not to make the line too sharp between the reduced and unreduced part, it is necessary to keep the negative in movement and now and then immerse beyond the point we desire reduced. This applies particularly

to the area around the lips which is most strongly overexposed. Once the lips begin to show very clearly, the wad of cotton can be used to good advantage, in order to avoid that sharp line. Some of our negatives unfortunately show such a sharp line of demarkation in spite of all our care. That always makes things look artificial.

The color of the negative gives the clue to your control over the bath when you use this formula. If a white deposit begins to show as an opaque substance on the negative, you know a few more drops of hypo needs to be added to the bath. If the reduction is not proceeding fast enough, or the negative begins to turn brown, more of the concentrated bleaching solution should be added immediately, drop by drop, until the white deposit begins to show. The solution should then be balanced by adding just enough hypo to stop that precipitation.

The author found the best way to treat the area over the larynx was to bend the negative into a bow, and then immerse just sufficiently to reach the part to be treated. The reduction for each of these areas should be carried far enough to leave the negative almost as transparent as a window.

After this process has been completed the whole negative should be submitted to an intensification process, in order to bring out a sharp contrast in the underexposed areas. About all the author can do is to refer the reader to any standard photographic manual for the needed process here. The double bath makes the process a very difficult one to control. It will probably be found that success will come only after considerable experience. This is probably one of the reasons why no study in X-rays of the vowel has thus far appeared in which the velum was unmistakably delineated.

Then after this intensification, the lips and larynx will again show overexposed. Hence there will be necessity for a repetition of the reduction process above.

Milimeter Stereograph Measurements Taken from Position of a = zero. Spinal Alignment of Negatives.

	Hyoid Head		Hyoid Prongs		Cornu		Thryoid		Throat		Epiglottis Tip		Velum	
	Horiz.	Per	Left	Right	Horiz.	Per	Horiz	Per	Horiz	Per	Horiz	Per	Horiz	Per
i	frd. 6	up. 2	up. 6	up. 2	—	—	frd. 5	?up. 2	frd. 5	up. 4	frd. 25	up. 5	bkd. 5	up. 2
I	frd. 4	up. 3	up. 4	up. 4	frd. 2	up. 3	frd. 4	up. 4	frd. 2	up. 4	frd. 15	up. 7	bkd. 3	up. 1
e	frd. 1	up. 4	up. 4	up. 2	—	up. 1	frd. 2	up. 3	frd. 2	up. 5	frd. 12	up. 7	bkd. 5	up. 2
ϵ	frd. 3	up. 6	up. 4	up. 4	—	up. 2	frd. 2	up. 6	frd. 2	up. 7	frd. 11	up. 7	—	up. 1
æ	frd. 2	up. 7	up. 8	up. 2	frd. 2	?up. 3	frd. 3	up. 6	frd. 2	up. 5	frd. 6	up. 6	bkd. 3	up. 2
a	All measurements are taken from position of this vowel as a norm.													
ə	frd. 4	dn. 2	—	dn. 1	bkd. 1	dn. 4	frd. 2	dn. 3	frd. 2	up. 1	frd. 9	dn. 3	bkd. 5	up. 4
ɔ	—	—	—	—	—	—	—	—	bkd. 2	up. 3	—?	—?	frd. 1	—
o	frd. 1	up. 7	—	—	bkd. 2	dn. 1	bkd. 2	dn. 1	frd. 1	up. 7	—?	—?	bkd. 3	up. 2
u	frd. 10	up. 5	up. 5	up. 3	frd. 1	—	frd. 3	up. 3	frd. 4	up. 6	frd. 20	up. 5	bkd. 5	up. 2

FIG. 35

CHAPTER IX

LARYNX, EPIGLOTTIS AND VELUM

> "Marichelle seems to be quite correct in insisting on the importance of the posterior cavity; it is the one into which the vibrations of the cords pass immediately and it undoubtedly acts as a strong resonator. It would be somewhat rash, however, to say that the most prominent resonance vibration comes from this cavity. It may be suggested that the vowel is a complex of resonance tones of which the pharyngeal tone would be one, the anterior mouth tone another, and so on."
>
> —MARICHELLE (1897) [1]

We have repeatedly called attention to the predominating importance of the back throat, or pharyngeal and laryngeal cavities and areas, in their possible function in varying vowel quality differences. The author has seen not only the resonator effect of the air volume to which Scripture refers. This naturally would be of essentially the same importance as that of any other cavity, front or otherwise, which might be coupled therewith; for the whole volume would inevitably be stimulated almost simultaneously, including all cavities where the air volume connected.

In addition to the air volume resonator effect, we must, however, take cognizance of factors involved in the influence surfaces might have in altering the quality; for the **air volume resonator,** as we have noted, can only be considered the **first** of those. It of course

[1] MARICHELLE, La parole d'après le tracé du phonographe, p. 27, Paris (1897), as interpreted by
SCRIPTURE, E. W. Yale Psychological Studies (1899) Vol. VII, p. 90.

has its pitch, or pitches, natural to the total air capacity and size of openings which are provided for each cavity. But in addition thereto, there are the surfaces, and these are subject to wider variations in this area than in any other; for it is completely lined with muscular tissue susceptible of varying degrees of tension. So we have to note a **second factor** inherent in the function of a constricted channel made up of **soft surfaces,** which inevitably operates to absorb the energy and **deaden the sound** as a whole; and this little narrow channel in the pharynx or velar area is regularly noted in varying degrees for all the back vowels except those in the *ə* (uh) series; whereas, the opposite effect, or a distension, is, speaking in general, manifest in the front vowels. This same function will inevitably result in a **third** factor of influence, which we cannot disregard; for the first effect resultant from forcing the sound through a narrowed cavity lined with **soft surfaces** will be to **suppress** the **high partials** and **produce a "mellowed" sound** — analogous to that produced by striking a piano string with a soft felt hammer; and the opposite would be manifest in a **distension** of the channel carrying with it a **tension** of the surfaces or hardening of the walls, thus **favoring the high partials, producing** the effect of what we call a **"metallic" sound** — analogous to that created when we strike the same piano string with a hard wooden or metal hammer instead of the soft felt one. The back vowels *ɔ* (aw), *o* (oh) and *u* (oo) especially, fall in the "mellow" group; and the front, *i* (ee), *e* (ate), *æ* (at) pertain to the "metallic" series; though where we are comparing the front series as to quality, the *ɪ* (it) and *ϵ* (met) might well be classified as "mellow" in comparison with *i* (ee) and *e* (ate) respectively; and we need note a similar differentiation for the *a* (ah),

U (foot) and other back vowels, where compared with such as *ɔ* (aw), *u* (fool, etc.

Like all theories, those of course call for considerable further experimentation before their truth or falsity can be established. The author has given them additional consideration in his Speech and Voice (Macmillan). But a large part of the evidence pertaining thereto is to be sought in physical and acoustic analyses, and these do not pertain to our present investigation which is primarily physiological.

After the present series of experiments had been completed and those theories developed, and in the course of writing up the results and delving into the history of vowel studies, the author encountered the above second-hand statement from Marichelle. If his statement, and the author's theories are correct, as the X-ray photographs would seem to imply, then we need turn more of our attention to the back throat, or pharyngeal and laryngeal cavities than has been customary in the past.

Perhaps the principal reason why Marichelle's study did not receive greater consideration, might be sought in the fact that we have heretofore had but meagre facilities for the examination of those back area processes. The laryngoscope, or little mirror on a handle, and the reflected light (commonly used by doctors) whose use calls for a depression of the tongue, and usually a grasping of the tongue tip with a towel or cloth and pulling it out, is of course impossible for an examination of normal speech processes. The broncoscopes, and phonoscopes, which go in over the top of the tongue and impede its normal movement are likewise defective.

The author's laryngo-periskop has made it possible to clearly see and photograph what was going on in

that back throat and laryngeal or glottal area, during normal speech and singing processes, without the impediment which prevented the others from doing so. Hence for the first time, we have been able to obtain photographs of that area as it was functioning in normal vowel and singing tone production. One of those series is shown in Figs. 37 to 48 inclusive.

It will be noticed that the epiglottis with its lower hump or cushion, would seem to be playing a very important part in the changing of vowel quality. This cushion of the epiglottis, as it creeps towards the arytenoids, can, along with the false vocal cords just above the ventricles of morgani, so narrow the opening above the vibrating cords themselves, as to form a very effective damper. In order to do so, this cushion needs merely to creep towards the arytenoids. And that is what it does in a more or less progressive way, as one passes from the vowel *i* (peep) shown in Fig. 41, thru the series ɪ (pip) Fig. 40, **e** (pape) Fig. 39, ϵ (pep) Fig. 38, *æ* (pap) Fig. 37. It also so closes up that opening, and functions as a decided damper, when one passes to very low pitches. For that reason, all these vowels were produced on the same pitch.

The author feels that Fig. 41 shows a spreading of those damping surfaces which may well account for much of the quality which we recognize in the "metallic" or "ringing" quality in the *i* (ee).

On the other hand, where we progress upwards to very high pitches, falsetto's and what the singer sometimes calls "tight" tones, the false vocal cords are seen to close in laterally and impinge so forcibly on the outside edges of the vocal cords themselves that they must radically change the type of glottal vibration. Three such tones are shown herein in Figs. 46, 47, and 48. Fig. 48 gives but a very inadequate idea of the "tight-

ness" which thus develops in the whole interior larynx from the epiglottis down. It will be noticed that the outside edges of the epiglottis have curved in laterally due to that tension. And the false vocal cords get so stiff, that they blanche and turn white. Then tension is so evident in every muscle that the whole area is set to vibrating, and hence the photograph shows nothing but blurred outlines. Can that very evident function be without effect on the quality of tone produced? Every muscle seems to get stiff. And one inevitably works against the other, until some of them get tired and suddenly relax, producing the well known break in such a singer's or speaker's voice. Such manifestations also inevitably develop in vowels and speaking voices when people get excited. The pitch gets higher and higher until we say they "squeak" and we designate their voices as "strident." Is that not evidence enough that certain qualities are created by the mere variation of surface function and manner of glottal action with the accompanying supraglottal damping and interference effect? Such qualities cannot be traced to air volume resonator function.

Now it is extremely interesting to observe that very low pitches show almost complete closure of the supraglottal opening we spoke of in the third paragraph above as appearing to be almost progressive in passing from *i* (ee) to *æ* (at). Where the voice descends to pitches bordering on the "growl" as it so often does in unaccented vowels of English where we have such radical variations of pitch rise and fall in our intonation, we have noted that the cushion of the arytenoids, epiglottis, and false vocal cords cooperate to form a damper over the vocal cord vibrations, and the resultant tends to produce a leveling of all vowels except the *i* (ee) to a quality which the ear hears as being much

the same. That fact may account for the present phonetic law operating in English to make all vowels in unaccented positions, with the possible exception of *i* (ee), turn into what we hear as an *ə* (uh). And where this latter falls in an unaccented position it tends to reduce to *I* (it), as in "intensity" (*IntEnsItI*). But once the pronunciation gets that far, even that may turn into an *ə* (uh) as in "possible (*pɒsəbəl*). Hence our "Once upon a time" (*uəns əpɒn ə taIm*); or "difficult to determine (*dIfəkəlt tə dətɜrmən*); or "Oh America, America!" (*o əmErəkə, əmErəkə*).

. . . . .

The position of the Hyoid Bone, Thyroid Cartilage, and other parts of the larynx, are all clearly indicated on the stereographic set of X-rays. Fortunately for us, this subject was a male with a decidedly prominent Adam's apple, in whom the ossification of the Larynx cartilages had progressed far enough to register clearly. The line of the Velum is also shown, and this is a happy discovery, since the position of the Larynx is usually postulated in its relationship thereto.

Fig 35 shows a table in which the computations have been made indicating the positions of those various organs reckoned for all vowels from the position of each organ on the X-ray negative for *a* (ah), where the outlines of the spinal column are used for alignment.

If we compare the position of the Thyroid Cartilage reckoned from the anterior-superior corner, with that

of the same corner of the Hyoid Bone head, it will be noticed that for practically all vowels there is very little difference between the movement made by the Hyoid and that of the Thyroid. The real exceptions are to be noted in the *o* (oh) and *u* (oo). For these two vowels there is regularly manifest a decided intervention of the hyoid muscles which connect with the chin, apparently for the purpose which the author has elsewhere noted, of at least in the last case, creating a decided pharyngeal resonator. And this function might well account for the failure of the Thyroid and Hyoid to move together as they appear regularly to do elsewhere.

Of course, as might well have been expected, the position of all those organs is shown in this subject to be essentially the same for *ɔ* (aw) as for *a* (ah). For the real distinction between those two vowels seems to be created by a throttling of the tone on *ɔ* (aw). through excessive constriction between the tongue and back pharyngeal soft walls.

In the case of all other vowels, though, it will be noticed that there is rarely a variation of more than 1 mm. in the measurement for the position of the Hyoid, and that of the Thyroid. And 1 mm. represents an extremely small excursion for such gross measurements, so it really cannot be considered as vitally important.

The **horizontal** movements are all **forward** from the position of *a* (ah) except the thyroid for *o* (oh) as follows:

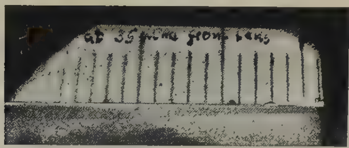
	i	*ɪ*	*e*	*ɛ*	*æ*	*a*	*ə*	*ɔ*	*o*	*u*
Hyoid	6	4	1	3	2		4	-	1	10
Thryoid	5	4	2	2	3		2	-	bkd. 2	3
Difference	1	-	1	1	1		2	-	3	7

The **vertical** movements are all **upward** from the position for *a* (ah) except both Hyoid and Thyroid for *ə* (uh), and the Thyroid for *o* (oh), as follows:

	i	*ɪ*	*e*	*ɛ*	*æ*	*a*	*ə*	*ɔ*	*o*	*u*
Hyoid	2	3	4	6	7		dn. 2	-	7	5
Thryoid	2	4	3	6	6		dn. 3	-	dn. 1	3
Difference	—	1	1	—	1		1	-	8	2

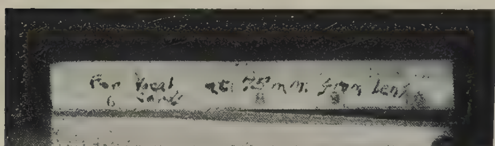
It will be remembered that for all vowels the pitch and loudness was kept as nearly constant as is possible. So that if there was here any physiological factor intervening to alter the sound, it could only have operated to change the vowel quality. This is apparently a characteristically average subject, and on the basis of the above observations pertaining to the movements in his organs, one would probably be justified in tentatively postulating larynx movements for all subjects, as being essentially that of the Hyoid except for the back vowels *o* (oh) and *u* (oo) or others of their type. Such a postulate will at least give much more accurate results than any measurements made with larynx capsules and apparatus such as the Abbé Rousselot was wont to use. For not only the movements of the Hyoid, but also those of the exterior throat muscles and skin must inevitably influence records made with the latter. Those who have been carefully trained in, and accustomed to make extensive use thereof will recognize the justness of this statement. And any reader can note that influence by palpation with his fingers over the exterior larynx area against which such apparatus is clamped. By placing the fingers atop the Adam's apple and saying "i . . . (ee) . . ." one can feel the tension of the hyoid

FIG. 36



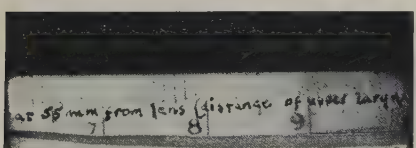
UPPER SCALE
(For Epiglottis Tip)

Use the lower edge for any measurements it is desired to make in the neighborhood of the tip of the upright epiglottis.



CENTER SCALE
(For Vocal Cords)

Natural size. Use the top edge for all measurements made on the vocal cords themselves or areas in their neighborhood.



BOTTOM SCALE
(For Upper Larynx)

Use the upper edge of this scale for measurements made on areas in the neighborhood of the upper larynx and lower epiglottis.

Scales for use on laryngo-periskopik Figs. 38 to 48 inclusive

FIG. 37

Vowel æ (map). Spoken by an American Baritone with as "metallic" a quality as was possible on a pitch of 100 d. v. sec. It will be seen that the Cushion of the Epiglottis (hump over the vocal cords at the top) is here strikingly closer to the arytenoids (or two lower bumps) than is noted for *i* (ee) Fig. 41. This soft cushion closure would tend to act as a damper on the high-pitched piercing partials of the glottal note and hence make this vowel æ (map) less "metallic" than the *i* (peep) of Fig. 41 for example.

The vowel here photographed may be spoken with a much "deader" quality. The vocal cords are then almost lost to view. First, because as happens also on very low guttural pitches, the cushion of the epiglottis is seen to move so close to the arytenoids as to leave a merest pin-head opening for the sound to get thru; and second, because the soft surfaced opening above the larynx is also much more closed than here, by the epiglottis.

FIG. 38. Vowel ϵ (pep) American Baritone. Prolonged somewhat but as in normal speech. Pitch 100 d. v./sec. controlled by tuning fork sounding in the ear of the subject. Note that the hump at the top or cushion of the epiglottis is closer to the bottom (back humps or arytenoids) than for *i* (ee) in Fig. 41 All the interior larynx muscles appear also to lie more loosely here than in Fig. 39 for *e* (aim), if one might judge by the shadows cast by the false vocal cords and cushion of the epiglottis. We are here looking down perpendicularly on the epiglottis and the vocal cords as they are seen from above. Compare Frontispiece, Fig. 1, for a better idea as to the relative relationship of these various organs.

The lens system comes in from the side thru a tube 4 mm. wide rising flush against the back wall of the throat or pharynx at 35 mm. above the tip of the epiglottis which would place it just below the tip of the uvula as shown in Fig. 1. The lens itself is 2 mm. in diameter, and deflects forward thru a series of prisms. Owing to the manner in which the tube is brought in, and its very reduced size, the tongue and speech organs are left free to move without impediment. This was not possible with the old laryngoscopic mirror on a handle used by the doctor, which made it necessary to pull the tongue out with a cloth; or with any of the old broncoscopes and phonoscopes which went in over the top of the tongue in such a way as to depress it and make normal speech totally impossible. So these photographs obtained with the author's laryngo-periskop, may be said to be the first which have thus far been made of unimpeded speech and song.

FIG. 39. Vowel *e* (fame) as spoken by American Baritone. Pitch 100 d. v./sec. A comparison with the position shown in Fig. 41 for *i* (ee) shows the epiglottis has lowered itself considerably. The upper hump or its cushion projects much closer towards the arytenoids. It will be noticed also, that the tip of the epiglottis has lowered so much as to make the edges clearly shown herein, whereas in the *i* (ee) none of this is visible. A radical difference in the tension of the muscular ridges running from the edges of the epiglottis to the posterior larynx may also be noted for the two vowels. The slope is very tense, and quite oblique for *i* (ee) whereas it is evidently so changed as to lie almost horizontal for *e* (ate). Since the oblique arytenoids are here involved, the effect upon the tonal quality cannot be overlooked. It is also interesting to compare the varying involvement of these muscles as manifest in the varying types of tonal quality shown in Figs. 46, 47, and 48. In the "pinched," "tight," or "strident" tones shown in 46 and 48, it will be noted that the contraction of these muscles...... (along with the others, especially the false cords, on the interior of the larynx) has become so great as to pull in the sides of the epiglottis, being as they are, opposed by the opposite pull from the Hyoid muscles.

FIG. 40. Vowel ɪ (pip). American (Baritone Voice). Prolonged as in normal speech. Pitch 100 d. v./sec. Note that the hump at the top has moved closer to the two arytenoids (or really cartilages of Santorini) at the bottom, than in the position it takes in Fig. 41. The cords also appear to be more bunched in lateral position. This would indicate a possible variation in the function of the fibers within the cords themselves, providing the observation is confirmed in a sufficient number of cases. At any rate we may well take cognizance thereof for the time being. For that may mean that the edges are less sharp and knife like for ɪ (pip) than for *i* (peep). The resultant would naturally be an original glottal tone which would be quite unlike in the two cases. For a rounding off and softening of the edges in the production of ɪ (pip) might well mean a suppression of the piercing high partials, and a consequent "mellowing" of the quality in the original glottal tone. In this connection it is of interest to note the fact we have called attention to in the text, viz. whereas ə (uh) is regularly substituted for all other vowels in the English unaccented position, when the *i* (ee) is unaccented ɪ (it) is most likely to be substituted.

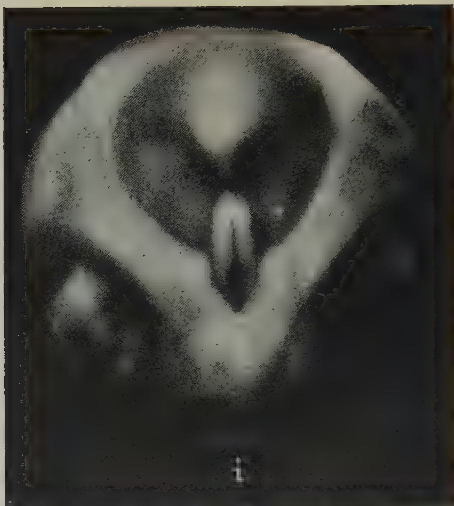


FIG. 41. Vowel *i* (peep). American (Baritone Voice). Prolonged but as in normal speech. Pitch 100 d. v./sec. Note how the hump at the top of the photograph (cushion of the epiglottis) takes a position well away from the vocal cords, freeing them from any damping effect from such soft surfaces and the air cushion in a confined cavity above them which seems so often to be formed when that soft hump closes up towards the arytenoids and cooperates with the false cords to leave but a very small opening thru which the glottal sound can escape. That air cushion would then be formed in the cavity which we know as the Ventricle of Morgani. The opening is sometimes reduced to a little hole not much bigger than a pin head. In such a case it is very evident that these soft surfaces would function to suppress the "metallic" high partials present in the original glottal fundamental, and you would say that the sound was "mellowed" or actually "dead." And it is of interest to note that this seems to be a regular process utilized on very low pitched notes. It would further appear that there are certain points or ranges in the scale where a radical shift or variation in the type of mechanism in pitch production takes place. This may account for what singers call their change of registers. Now identically the same function is quite regularly noticed in vowel production, for as we move thru the series from *i* (peep) to *æ* (pap), this hump shows a progressive creeping towards the arytenoids. Compare Fig. 37. Where it is well out of the way, as here in Fig. 41, we might

expect the original glottal tone to have more high partials present, and consequently be more "metallic," in its quality than any of the other vowels. In discussing the theory involved, we have elsewhere indicated a possible compensation or alternation between this function and that resultant from a constriction of the cavity against the hard palate and teeth. That would appear to justify García's early contention, that on very loud and high pitched notes the singer should open the front cavity more than usual to prevent strident quality. It will be remembered he was the first to be able to see the vocal cords.

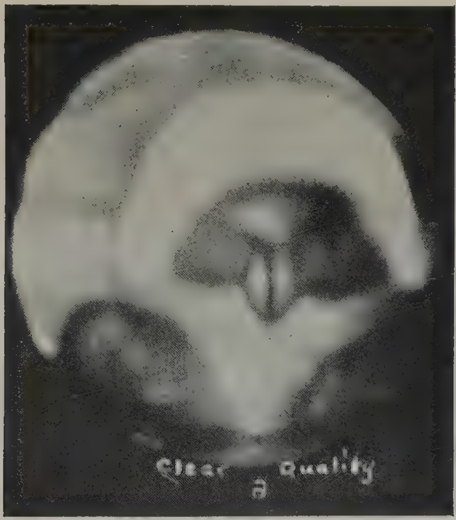


FIG. 42. Vowel ə (uh-pup) American (Baritone Voice). Prolonged as in normal speech. Pitch 100 d. v./sec. This vowel seems to vary its quality from "clear" or "bright" to "mellow" or "dead." As it begins to approach the latter, the lips close, or the throat cavity soft surfaces narrow down more and more, and the hump at the top (i.e., cushion of the epiglottis) moves closer towards the arytenoids (or two bumps at the bottom center) thus acting as a damper to the vibrations of the vocal cords. If excessively deadened, this action becomes so extreme we can no longer see the cords.

As has been noted in the text this vowel regularly substitutes in the unaccented position of English for all other vowels. A possible physiological reason is there indicated.

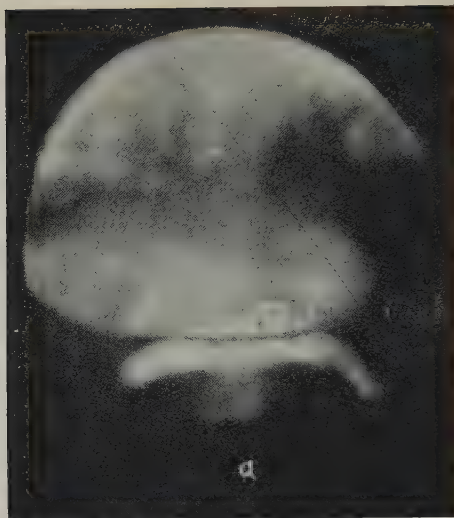


FIG. 43. Vowel *a* (ah-pop). Spoken by an American Baritone. Pitch 100 d. v./sec. It is of interest to note that the tongue and epiglottis have almost closed the opening thru which the voice has to escape. The median opening is not more than 2½ mm. wide. So far as the view of the interior larynx is concerned therefore, this would be the last vowel one should use. But it has become almost a tradition for doctors to use that vowel in order to look into the throat. All of that came about because of the fact that the front position of the tongue was immaterial for the production of this vowel, and so it would be most likely to lie flat in the mouth where you opened the jaws wide, especially if a little pressure was used from some kind of depressor. But since the back cavity closes up for this vowel, as is evident here, it became necessary to grab hold of the tongue tip and pull it out during such phonation, in order to get a view of the interior of the larynx. The resultant vowel then would seem to be nearer ə (uh) than *a* (ah), and at times it may well pass into ϵ (eh) since as we move thru the series towards *i* (ee) the back cavity gets progressively wider and wider. The latter vowel is almost sure to close up the front mouth cavity in spite of any depressor, however, whereas the same might not be said of ϵ (eh). It would consequently appear, that the doctor's request formula for observation of the interior larynx, "say ah," should be changed to "say eh" and the patient be requested to speak as loudly as possible.

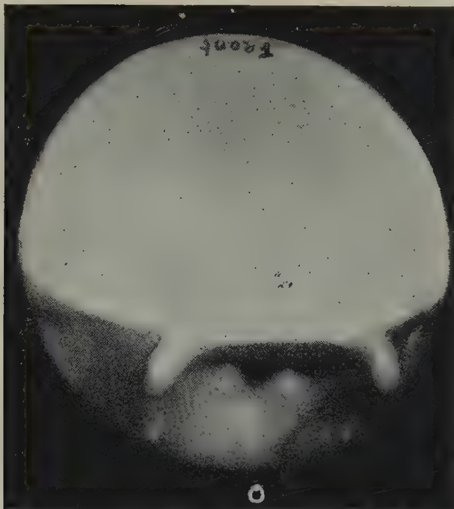


FIG. 44. Vowel *o* (pope) American (Baritone Voice. Normal spoken vowel as prolonged. Pitch 100 d. v./sec. The big white area is the tongue. The curved tips are all that can be seen of the epiglottis. The two little bumps in the lower center are formed by the cartilages of Santorini, mounted on, and usually designated herein as the Arytenoid Cartilages. While the Vocal Cords are not visible in this subject, there are times when parts of them can be seen in the production of this vowel, providing the individual works hard to bring it about, by making the vowel mostly with the lips, and attempting to put the tongue as nearly as possible in the position for *i* (ee). But the same attempt has thus far failed to bring results for *a* (ah).

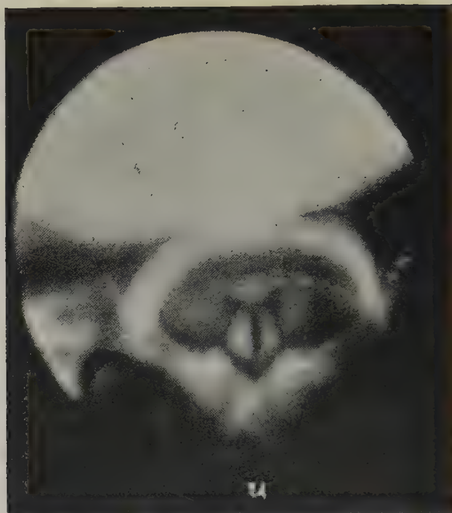


FIG. 45. Vowel *u* (poop-boom). Spoken by an American Baritone on a Pitch of 100 d. v./sec. with the lips decidedly puckered. By so doing it is possible to regularly see the vocal cords. Otherwise the view is shut off by the epiglottis as in Figs. 43 and 44. The author has had to etch one corner of the vocal cords on the upper left here, in order to indicate in the cut, what seemed to be their edge in the film, and all in all this is about the most unsatisfactory photograph in the group but it is given in order to complete the series for this one subject.

FIG. 46. Vowel *e* (fame). American Baritone Pitch g^2 767 d. v./sec. Sung very loudly with purposely "strained" quality — what the singing teacher calls a "tight" voice. Note that this seems to be caused not so much by the "tongue getting into the back of the throat" and pinching the tone as by a tension of those laryngeal muscles which should be trained to relax. Hence a purposeless pulling of one set against the other results. Something of this same tendency may result where the singer gets excited, or is tired, or unstrung to such an extent as no longer to have the muscles under proper control and coordinated in their function as they should be. Under such circumstances, where one pulls against the other something must finally give way, and where it does so abruptly, we say the voice "breaks."

Here it will be noted that all muscles are so tight the whole area trembles and shows with fuzzy outlines. Even the edges of the epiglottis curve in from the contration of the oblique arytenoids and perhaps in consequence of the simultaneous counter pull of the Hyoid muscular fibers attaching the tongue and epiglottis to the chin, there being also involved an extreme tension of the aryepiglottic all of which should be relatively relaxed. Compare the view with that of Figs. 43 and 44 to see how the tongue looks when it does get into the back part of the throat, as it normally and naturally does for the production of an *a* (ah) even where sung by the finest trained voices. Compare also Fig. 39 for a normal spoken *e* (fame) and with Fig. 48 for a similar "tight" tone on *i* (peep).

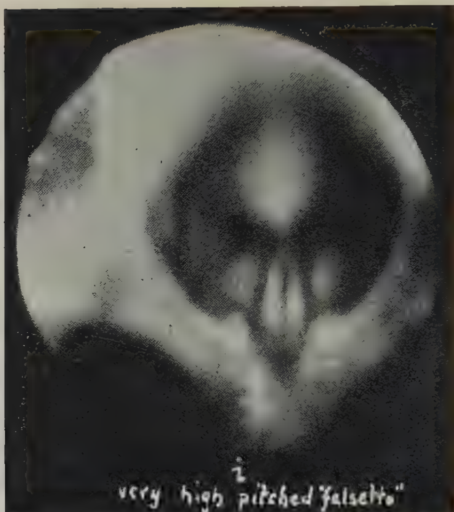


FIG. 47. Vowel *i* (peep). American Baritone. Sung very softly with pleasing "falsetto" quality on g^2 767 d. v./sec. The author is not sure how to interpret what appears. The muscular tension is evidently not equal thruout the length of the cords; and it would seem that but a part of them are vibrating. Is it that half nearest the arytenoids? A stroboskopik examination would probably be necessary in order to decide the point and the author's was not rigged up for this piece of apparatus at that time. Compare with Fig. 48 produced on the same pitch, but with "strident" quality; and with Fig. 41 for the same vowel produced in normal speech on a very much lower pitch. Note the entirely different muscular function involved in the three cases.

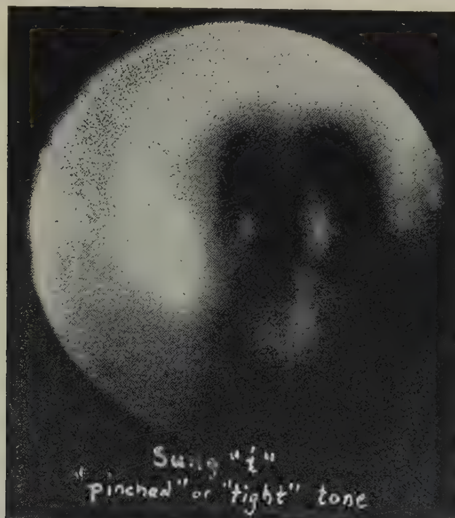


FIG. 48. Vowel *i* (peep). American Baritone. Sung very loudly on g^2 767 d. v./sec. with purposely "strident" quality to illustrate the so-called "tight" or "pinched" tone commonly heard on very high pitches where produced by poor or untrained voices; characteristic also of speech in those who speak or sing under stress, or highly wrought up nervous strain; also of those unaccustomed to speak from the platform; or in most people who enter into such angry dispute as to lose all control of their normal cultured speech modulation; regularly heard also in the as yet unmodulated voices corrected by trained culture, as in children who are naturally boisterous, or even in mature women who have never had the advantage of cultured training. Under such circumstances the voice regularly gets higher and higher pitched; or the individual sings with more and more "strident" quality; both of which come from increasing tension of the muscles; the latter from a pulling of one set against the other, or the manner in which one gets in the way of, or prevents the free function of the other. This last manifestation is very evident here; for as will be seen the false vocal cords impinge laterally upon the true, in such a decided manner as to prevent their free vibration, force them to clash together in order to overcome the load, and so overwork them as to irritate and inflame and cause the gathering thereon of mucus which will all make for a rasping, strident quality, in which the harsh, metallic, high-pitched noise concomitants are so evident as to overshadow the harmonic musical elements. Under the operation of all this false function, it is perfectly natural that the voice in the end should "break," for a time of exhaustion must come.

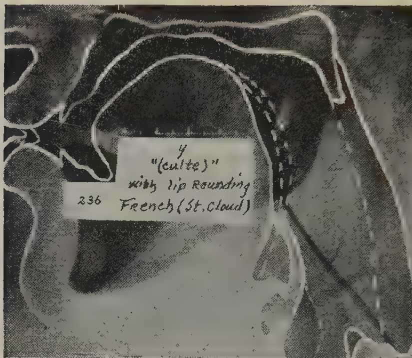


FIG. 101

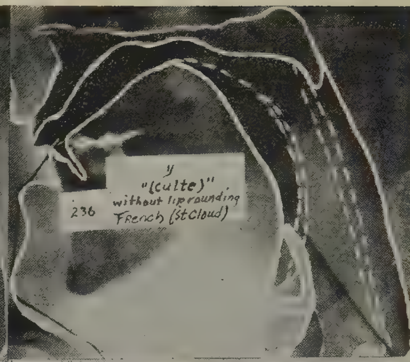


FIG. 102

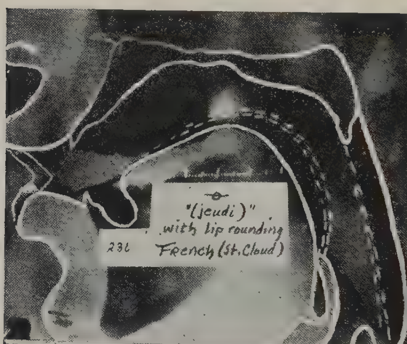


FIG. 103

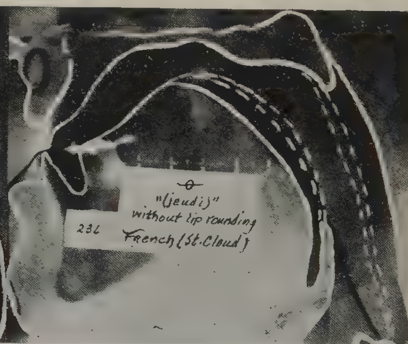


FIG. 104

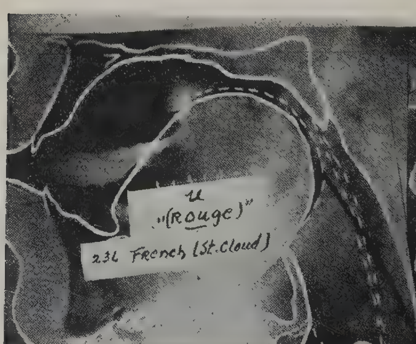


FIG. 105

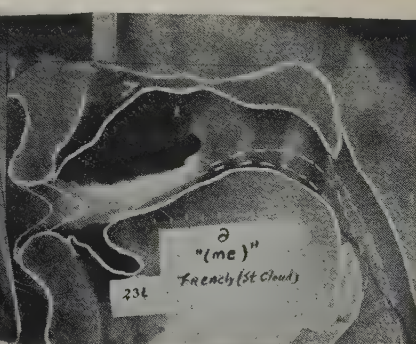


FIG. 106

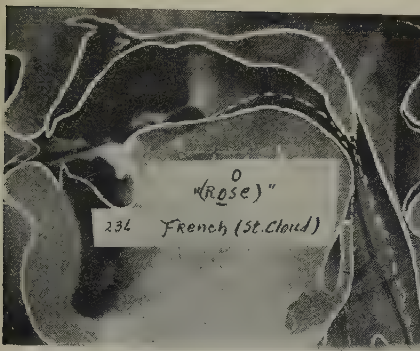


FIG. 107

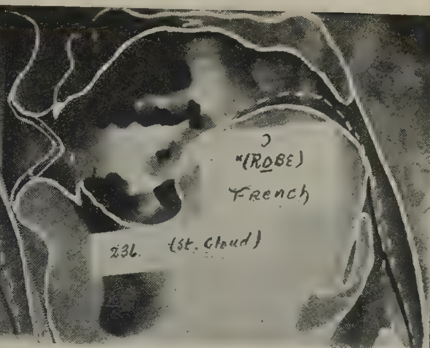


FIG. 108

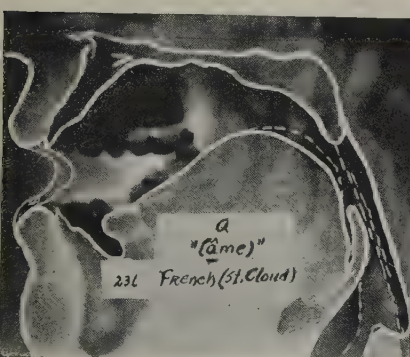


FIG. 109

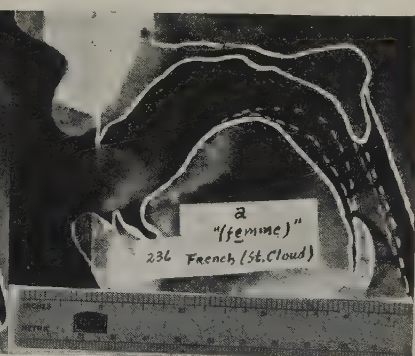


FIG. 110

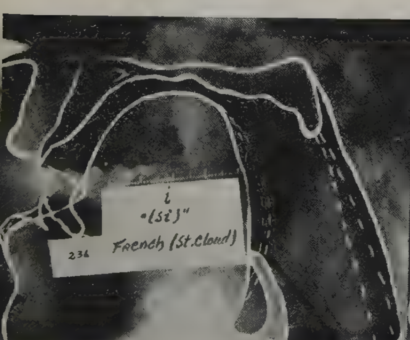


FIG. 111

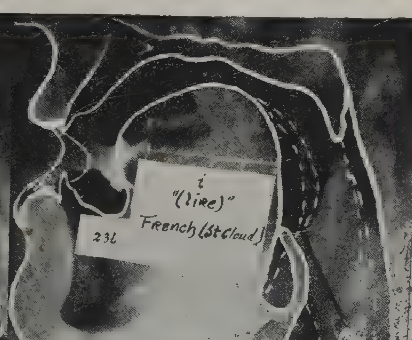


FIG. 112

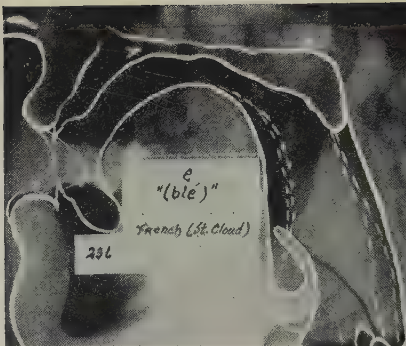


FIG. 113

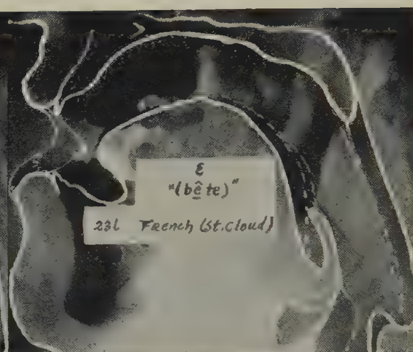


FIG. 114

(NOTE: This group of vowels produced in French by a cultured Parisian lawyer born on the outskirts, in St. Cloud, are all reduced exactly the same amount. So the scale printed with Fig. 110 may be used for all. The reader will recognize the epiglottis as the curved up white tongue in the lower right hand corner. Below it is the dark wish-bone like shadow called the Hyoid. Our measurements on Figs. 230-239 show that the Vowel movements of the exterior larynx generally correspond to those of the Hyoid.

This subject has produced the rounded vowels with and without lip rounding both with good quality hard to distinguish from each other.

Note that the most radical differences occur in the back throat. The front mouth is essentially the same size for *i* (lire) Fig. 112, and *e* (blé) Fig. 113.

muscles, whose movements must inevitably be manifest in records made with the Abbé Rousselot's apparatus.

So that if we can take our movement records from the image of the Hyoid, for all vowels except those above mentioned, much more reliable records can be obtained than those customarily had. And we can get them for female and young subjects as well as the older males with well progressed ossification of larynx cartilages. The author for his part will make regular use of the same in his future examinations, until the assumption of such relationship for vowel quality between the movements of the Hyoid and Thryoid at constant pitch, is proved to be more unreliable than is shown in the above.[1]

The horizontal movements of the Hyoid, in particular, indicate as has been stated, a distension of the lower pharyngeal cavity. It is therefore not surprising to note that the greatest excursion from the position of *a* (ah) as the norm, takes place in the production of *u* (oo) and *i* (ee). So far as the other vowels are concerned, it may be said that variations of 1 mm. in passing from vowel to vowel cannot be considered as of any great possible importance in varying the quality of one in comparison with the other. And so no comment need be made on them. The figures speak for themselves.

The perpendicular movements are more striking. As indicated in the preliminary comment on the tabulation of vertical movements, all movements of both Hyoid and Thryoid are upward from the position of *a* (ah) as the norm, excepting *ə* (uh) and possible *o* (oh). And those upward movements mean that the pharyngeal cavity is shortened. Before beginning this commentary the author would have suspected that the

i (ee) would show the longest throat cavity. So it comes as a distinct surprise to note that the ə (uh) indicates the only movement downward, and hence the longest throat cavity. That surprise is not minimized in the observation that the *a* (ah) and ɔ (aw) show the two next lowest positions; and we are caused to wonder all the more when we see that the *æ* (at) which we would expect to fall in the same category with *a* (ah) and ɔ (aw), not only does not, but actually rises higher above the position taken for *a* (ah) than does any other vowel (judged by the position of both the Hyoid and Thryoid), and is thus shown as having the shortest distance from Hyoid to Palate of the group. Then we are inevitably struck by the fact that for *o* (oh) the Hyoid rises quite as high as for *æ* (at) but the Thryoid drops 1 mm. below the position for *a* (ah) or ɔ (aw). Why? The author sees no answer in terms of any of the theories now before us, and is not willing to advance others until more data is at our disposal.

Judged by the position of the Hyoid, those vowels in question stand in the following order, from the lowest to the highest:

0	2	4	5	6	7	8	9	9 mm.
ə (uh)	*a* (ah) ɔ (aw)	*i* (ee)	ɪ (it)	*e* (ate)	*u* (oo)	ɛ (eh)	*o* (oh)	*æ* (at)

There are not such consistent differences between the positions computed for the Thryoid, to-wit:

0	2	3	5	6	7	9
ə (uh)	*o* (oh)	*a* (ah) ɔ (aw)	*i* (ee)	*e* (ate) *u* (oo)	ɪ (it)	ɛ (pet) *æ* (at)

And since the registration point is not so reliable as is the sharply delineated projection of the Hyoid, the author would prefer to take measurements of the Hyoid as indicating the most valuable information. But again

he must say that it is not so much the steps of a millimeter difference from vowel to vowel which is of importance, as the final progression shown by the extremes.

Where the throat cavity is considered as a resonator it might be well to compare these with the computed frequency order as ascertained by Paget, (see Fig. 2), Crandall (Fig. 3), and Liddell 263.

Now so far as the resonator itself is concerned, the perpendicular movements of the larynx and velum must inevitably be considered of importance, for they elongate or shorten that back air column. In the right hand column of Fig. 35 are given a series of measurements on the positions of the velum taken for the stereographic set of vowels. In the author's report in 1924 before the M.L.A. in New York, he expressed an opinion that the movements of the velum showed wider excursion than is here manifest. It is evident that if the back part of the tongue rises it may have a tendency to carry with it the palatine arches which so far as we are concerned, form the essential part of the velum. And that might account for the horizontal movement on *u* (oo) for that part of the velum where they attach, and where it begins to turn downward in the projection known as the uvula, which is the point chosen in order to make these measurements. It will be noticed that aside from that, the greatest movement in this direction is manifest for the vowels *i* (ee), *e* (ate), and *ə* (uh); and this means that the enmeshing effect of the soft surfaces provided by the pillars of the fauces (or palatine arches) and velum at that point is more nearly eliminated for these vowels than for the others. It will be remembered we above pointed out the fact that when such surfaces were distended and tensed as they would be in this case, the effect would be

to favor the high pitched "metallic" partials and make the sound "brighter" more "clear-cut" and "ringing." Such an intervention at this point might therefore go far to differentiate the quality manifest in *i* (ee) and *e* (ate), from the deader or more "mellow" quality heard in *I* (it) and ε (pet) respectively.

We need also note that the real movement differentiation in the velum is one from back to front, rather than up and down. In commenting on nasalization the author has already called attention to this fact, which is quite contrary to the general conception. This would make it appear that the muscle of the uvula which passes up over the velum and attaches to its process on, or extension of the hard palate, may be of more importance than we have been wont to ascribe to it.

But that is not intended to imply that the up and down movement does not regularly take place. We merely desire to note that the nasal opening may be made in the other manner and that the front-back shift of those velar surfaces should be carefully noted.

. . . . .

In the tables of measurements covering the X-ray vowel positions shown from Figs. 101 to 229, we have given the anterior posterior dimensions of the opening formed between the tongue or epiglottis and the pharyngeal wall, wherever it would seem to have been vital in forming an opening of such a sort as to create a definite division in the resonating cavity. Where it narrows considerably it is evident that three resonances might easily be provided; the laryngeal, as well as the pharyngeal, and buccal. For that reason we may say that the position taken by the epiglottis and back tongue at that point might well be considered as of as

much importance as that taken by the tongue in the upper buccal cavity; for both vary the resonating cavity. We have particularly noted the constriction of this epiglottal opening in the production of the *a* (ah) series of vowels.

The laryngo-periskopik photographs also show the more or less regular progressive change in the opening formed by the epiglottis. It will be noted that in general this is anterior-posterior (or from front to back) rather than from side to side. This makes the median section position shown in the X-ray the one of most vital importance to our consideration, so far as narrowing of the epiglottal opening in its effect on the air volume resonators is concerned.

Epiglottis—Lateral Motion

One of the very few research comments thus far made in regard to the positions taken by the epiglottis in the production of vowels is found in a work[1] of the Abbé Rousselot:

> "on sent une légère tendance des bords à se replier sur eux-mêmes;—*ó*, l'angle est semblable à celui de l'*é;* — *u* l'angle s'ouvre beaucoup et l'épiglotte se creuse nettement en forme de tuile; — *ú*, l'angle s'agrandit encore et les bords continuent à se rapprocher."

What he means is not exactly clear. It would appear that he wants to imply a narrowing of the epiglottal opening into the larynx, resulting from a curving-in of the outside edges. This would be in lateral (or horizontal) plane at right angles to the opening shown in sagittal section. If that observation is correct it is of considerable importance, for such a constriction might change the pitch of all the supra-glottal cavities.[2]

An examination of Figs. 37-45 will show that the

[1] Rousselot, L'abbé Principes de Phon. p. 723.

[2] cf. PAGET, Sir Richard. *Artificial Vowels.* Proc. Roy. Soc. A, Vol. 102 (1923) p. 755, 762.

epiglottis is rising and lowering in a varying manner for differing vowels.

Looking at these vowels from the most acute-angled superior-posterior position it is possible to take, what shows in Figs. 43, 44, and 45 is all of the epiglottis which can be seen from above.[1]

The top scale Fig. 36 should be used for making measurements on these three vowels of Figs. 43, 44, 45, since it is adjusted to the lens correction for the upper edges of the epiglottis. For the vowels in Figs. 37, 38, 39, 40 and 41, the lower edges of the epiglottis may be seen, and if it is desired to measure at that point, the scale on the bottom will be used. So measured from right to left, they are as follows: (at the lower edges of the epiglottis on an American baritone).

Fig.	41	for	*i*	30 mm.
	40	"	*ɪ*	32 mm.
	39	"	*e*	31 mm.
	38	"	*ɛ*	33 mm.
	37	"	*æ*	34 mm.

The change of 1 mm. from vowel to vowel, is too suspiciously regular, and is such a small shift that it cannot be of any great importance. It is interesting to note that the progression is *i, e, ɪ, ɛ, æ.* Compare that with a similar observation which might be made as to the increasing size of the front palatal cavity. (See Figs. 163, 165, 164, 166, subject 291, for example). It looks very much as if this variation in Figs. 37-41 were the perfectly natural result of the spreading of the lower edges consequent on the lowering of the tip of the epiglottis towards the pharynx. Then, too, we have measured from the outside edge, and the point chosen is more or less arbitrary. As the

[1] The sagittal section positions of the tongue and epiglottis for the back vowels, in Figs. 43, 44, and 45, would have been very much that of Figs. 141, 144, and 146, in Speech and Voice (Macmillan).

epiglottis slopes towards the upper edges and tip, it gets narrower. Since nothing but the upper edge shows for the back vowels, any measurements obtained there would be even more dubious. This is especially true where computations fall within the scope of a millimeter or so, for a too radical small variation in such measurements could take place depending on how high up towards the tip you chose your points for measuring. But there, as best as can be ascertained, the measurements for all three at the point where the epiglottis begins its most radical curve downward, are the same being:

Fig. 43 which is	*a*	15 mm.
44	*o*	15 mm.
45	*u*	15 mm.

We are almost forced to the conclusion, therefore, that most of the constriction in the opening between the larynx and pharynx cavities will be sagittal in anterior-posterior direction, rather than lateral. However, that generalization must be modified in cases where the edges of the epiglottis touch the back pharyngeal wall, for since it usually narrows towards the tip, even the lateral dimensions of this aperture might then be considerably decreased, depending on how high up towards the tip the contact took place. These cases will generally deal with *a* as in Figs. 43, 109, 140, 141, but may include *o*, *ɔ*, *ə*, etc. See Figs. 44, 142-145.

So far as the interior walls are concerned, an exception may also be noted in the type of tone photographed in Figs. 46 and 48. These are the singer's so-called "pinched" or "tight" tones. Perhaps in speech they may well correspond to the so-called "harsh" voice, or, better still, "New England twang." It is apparently caused primarily by a decided con-

striction on the interior of the larynx. As will be noted in Fig. 48, the false vocal cords then impinge forcibly on the true vocal cords and prevent their free vibration. Here the tenseness seems to be manifest also in the curve of the epiglottal edges.

If the Abbé in his figures: [1]

"Position de repos, *zéro;* — *a* II^{mm}, *è* 10, *é i* 9; — *œ* 7, *œ* 6, *œ u ú* 5; — *à* 10, ò 9, *ó* 8, *u* 7, *ú* 5."

refers to the opening between the epiglottis and the pharynx, the experiments herein do not agree. Quite the contrary would be true, since *a* usually shows the narrowest opening. Compare Figs. 109 and 110 with 105 and 111-114. If he means them to apply to the vertical rise and fall of the tip, the same thing holds true, as a comparison of the last above cited figures will show, cf. Fig. 35, a table which contains measurements for the perpendicular height of the epiglottal tip in the stereographic X-rays. This stands also to reason. As the tip lowers, the opening between the epiglottis and the pharynx will close, though of course a back tipping towards the tongue might lower the tip ever so slightly. [2]

The author cannot see how the relationship between the epiglottis and the tongue could affect the vowel quality. And if not, why cite it. Of course, a small cavity might be formed between the two. This would have its "natural period," which would be characterized by a more or less high pitched tone, depending upon its total size and opening. If the epiglottis touched in the center, it might even have two openings, where both it and the tongue were convex. Such seem to be indicated in Figs. 101, 102, 105, 111, 112.[3]

Where the edges of the tongue curve at that point,

[1] *Op. cit.*

[2] In both this and the preceding a vertical lowering is meant.

[3] cf. Speech and Voice. Figs. 121, 122, 132, 134.

they might well touch the epiglottis at both sides, and if the center did not touch the tongue at that point, a single opening would thus be formed. This latter type may be indicated in Figs. 114.[1]

Where center contact takes place, and the space is small, however, it may be doubted whether a cavity exists which is capable of being stimulated. Cf. Figs. 108, 109, 110.[2]

Even where no contact is indicated, their stimulated existence may be seriously doubted; cf. Figs. 103, 104, 107.[3]

It will be noted that where any of these types of cavities exist between epiglottis and the tongue, the vowel being produced is usually in the front series. See Figs. 101, 102, 111, 112-114.[4]

But compare this observation with the facts shown in Figs. 104,[5] in which such an epiglottal cavity is indicated for back vowels. As a matter of fact, its creation would seem to be dependent on the distension or contraction of the larger pharyngeal cavity within which it is found. It will be remembered that the distended type of throat cavity is most characteristic of front vowels. See Figs. 101-4, 111-114.[6] Compare with Figs. 106-9.[7]

But such a distension very often takes place in the production of back vowels such as *u*, and even *o*. Where so pronounced, the epiglottal cavity is almost certain to be manifest. See Fig. 105.[8] Yet the *u* is the very last of the vowels in which we should expect

[1] *Ibid.* Compare Figs. 116, 117, 118, 125, 127, 137, 138, 148. Speech and Voice.
[2] *Ibid.* Compare Figs. 129, 130, 131.
[3] *Ibid.* Compare Figs. 119, 120, 137, 133, 141, 142-147.
[4] *Ibid.* Compare Figs. 115-118, 125-127, 137, 138.
[5] *Ibid.* Compare Figs. 121, 122, 123, 124, 135.
[6] *Ibid.* Compare Figs. 115-118, 125-127, 137, 149.
[7] *Ibid.* Compare Figs. 119-122, 129-134, 141-5.
[8] *Ibid.* Compare Figs. 123, 135.

to find an extremely high-pitched quality tone of that type present. [1] Aside from this fact, it will be noticed that the same vowel may manifest some such epiglottal cavity in one speaker and not in another.[2]

Where the tongue in the neighborhood of the epiglottis backs up toward the pharyngeal wall, the tendency is to make contact with the epiglottis. It may then be expected to eliminate any such cavity. Where the opposite movement of the tongue takes place, the space between the epiglottis and the tongue may increase. The angle created must surely be immaterial, except as the size of the cavity might thereby be changed. But Figs. 111, 112, 113, 108 cf. with 113 do not conform to the Natier-Rousselot observations pertaining to even this question. And as stated above, it is difficult to see how any vowel quality effect can be ascribed to the space between the epiglottis and tongue itself.

What is important, without any question of doubt, is the function of the epiglottis in narrowing the aperture between the laryngeal and pharynx cavities. If the arching of the tongue divides the upper cavity in two parts, and the epiglottis goes back far enough to create a very narrow opening between the larynx and the pharynx, at least three distinct resonance chambers are provided. Where such a vowel position is manifest, as in Fig. 116,[3] we would be justified in expecting, triple rather than just the double resonance most investigators have been talking about since the time of Wheatstone.

[1] See CRANDALL, Dr. Irving B. *Sounds of Speech.* Bell Telephone Laboratories, pub. B. 162-1. Tables and Fig. 14, p. 18. MILLER, D. C. *Science of Musical Sounds.* N. Y. 1922, p. 226, Figs. 165, 166.

[2] Compare for example Figs. 105 and 135 with 146: 121 with 106, 131 and 142 — that is those figures in which it is present, with the corresponding vowels of other speakers in which the epiglottal cavity is not present as shown here and in the author's Speech and Voice (Macmillan).

[3] And *op. cit.* Figs. 120, 124-127, 137-145.

While he does not actually depict the results of such observations in the form of sagittal section diagrams, the Abbé Rousselot also makes certain comments on the position of the larynx during the production of various vowels.[1]

"D'après les mesures prises sur moi par M. le D^{r} Natier, la position moyenne est celle de l'*a*; de là jusqu'à *ú* le larynx s' abaisse, et jusqu'à *í*, il s'élève. La position de repos étant *zéro*, on a successivement: *ú* 4^{mm}, *u* 6, *ó* 7, *o* 8, *ò* 9, *á* 10; — *a* 11; — *à* 12, *è* 12,5, *e* 13, *é* 14, *i* 15, *í* 17. Cette élévation progressive du larynx répond *à* la division des voyelles en *graves* et *aiguës*. Sont graves: *ú*, *ó*, *á*, *è*, *i*; aiguës: *u*, *ò*, *à*, *é*, *í*, les notes caractéristiques des premières voyelles étant respectivement moins aiguës que celles des secondes. Les voyelles *o*, *a*, *e* restent moyennes. Quant *à i* et *u*, rien n'empêche *de les* considérer aussi comme moyens. La série antérieure labiale ne cadre pas exactement avec la série non labiale : le larynx descend plus bas et monte plus haut. Ainsi nous avons : *œ* 9^{mm}, *œ* 12, *œ* 13, *u* 17, *ú* 19. Les nasales présentent les égalités suivantes : *ā* = *á*, *ō* = *o*, *ē* = *è*, *œ* = *œ*."

"La projection du larynx dans le sens horizontal s'accorde exactment avec la division en trois séries que nous avons établie dès l'abord. Elle est de 3^{mm} de l'*à* à l'*í*, de l'*a* à l'*ú*, de 4^{mm} de l'*á* à l'*ú*, le point de repos étant *zéro*, les *a* à 2^{mm}, *í ú à* 5, *ú à* 6; les autres voyelles se partagent, à peu près également la distance intermédiaire.

"L'élévation du larynx se constate également par l'intérieur. Ainsi l'épiglotte, qui n'apparaît chez moi qu'avec *ò*, 1^{mm} audessus du point de repos, monte successivement : *á* 2^{mm}, *a* 3, *à* 5, *è* 7, *e* 9, *é* 10, *i* 12; — *œ* 5, *œ* 6, *œ* 7, *u* 8, *ú* 9.

Rousselot does not say how Dr. Natier obtained his results but since he prints a kimograf tracing on p. 725, it is presumed they were ascertained by that means. If so they must have been recorded by a larynx attachment steadied by the neck, chin or shoulders. It is to be noted that under his tracing he refers to the apparatus in Fig. 40 modified.

[1] ROUSSELOT, L'abbé Principes de Phonétique Exp. Paris 1908 ed. p. 721. In the 3rd last line of the first par. above the 1st œ carries a grave and the 3rd an acute accent; and in the last line the first œ has a nasal and the second a grave accent. In the last par. the first œ has a grave and the last an acute accent.

The regularity in progression through steps of an almost uniform 1 mm. between vowels, looks suspicious. A movement of 1 mm. is an extremely slight shift in such a large organ as the larynx displaced in vertical direction. Then, since the slightest movement of the body, chin, head, or exterior muscles of the neck and shoulders may be susceptible of influencing the recorder, it is hardly clear how accurate results could be obtained.

Nor has he stated how Dr. Natier obtained his results in observations of the epiglottis. It is presumed that he make use of a laryngoscope. Since the epiglottis is on the interior with no means of sensing its movements on the outside,[1] one has been heretofore constrained to so observe it. Such an observation had to be through the buccal cavity. And for that purpose, the tongue must be depressed or pulled out somewhat with a towel.[2]

If they were so made, his figures for most of the vowels are quite incomprehensible, since vision during any ordinary articulation is totally impossible. And if he used his finger he must of necessity have been forced to guess. The Abbé further states:

"Chacune des parties observables du larynx change de forme pour chaque voyelle, et nous ramène à nos trois séries.

L'épiglotte, observée par M. le D[r] Natier chez un sujet qui s'efforçait de dire toutes les voyelles sur le même ton et avec une égale intensité, a paru s'étaler sur le base de la langue pour les voyelles ouvertes (les *a*), puis s'en séparer progressivement en formant avec elle un angle d'autant moins aigu, et se repliant d'autant plus par les bords que, dans chaque série, la voyelle était plus fermée. L'angle est aigu pour *è*, s'ouvre pour *é*, et prend pour *i* la forme d'un *v*, (cf. fig. 94 et 99), qui devient plus net encore pour *í*, quoique la base de la langue soit rejetée

[1] We mean, of course, where the X-ray is not made use of.

[2] The specially devised laryngo-periskop used for the experiments herein, is the only apparatus the author knows of which permits of supraglottal observation without being forced to look in through the buccal cavity over the top of the tongue.

en arrière. La correspondance des deux séries antérieures diffère un peu de celle que nous avons reconnue d'après les mouvements de la langue, la contraction étant respectivement plus considérable dans les labiales: *œ* se rapproche de *é*; *œ* de *i;* les bords de l'épiglotte sont plus repliés pour *u ú* que pour *i í*. Même observation pour les voyelles postérieures: *ô*, on sent une légère tendance des bords à se replier sur eux-mêmes; — *ó*, l'angle est semblable à celui de l'*é;* — *u*, l'angle s'ouvre beaucoup et l'épiglotte se creuse nettement en forme de tuile; — *ú*, l'angle s'agrandit encore et les bords continuent à se rapprocher.

"En conséquence, l'epiglotte se redresse sur sa base pour *a*, puis il s'abaisse légèrement pour les voyelles antérieures non labiales, d'une façon très sensible pour les autres séries. Voici les rapports que M. le D^{r} Natier a cru pouvoir mesurer. Position de repos, *zéro;* — *a* 11^{mm}, *è* 10, *é i* 9; — *œ* 7, *œ* 6, *œ u ú* 5; — *à* 10, *ò* 9, *ó* 8, *u* 7, *ú* 5."[1]

The facts shown by our experiments reported herewith sustain but very few of the statements made in the above quotations.

If the Natier-Rousselot experiments were made with any type of larynx capsule the registration was probably decidedly influenced by the hyoid muscles. Below are given some such measurements taken from the X-rays (Figs. 101-114) of a French subject (Paris lawyer, born in Saint Cloud), using therefore the anterior-superior corner of the hyoid bone. It will be noted that from *a* as a zero point, there is indicated a lowering for all vowels and no raising for a single one:

All lower			(lire)					
from position of	$i^{dn.}$	7 mm.	$i^{dn.}$	8 mm.	$e^{dn.}$	14 mm.	$\epsilon^{dn.}$	10 mm.
	$u^{dn.}$	15 mm.	$o^{dn.}$	4 mm.	$ɔ^{dn.}$	6 mm.	$ə^{dn.}$	4 mm.
a					$(y)^{dn.}$	8 mm.	$(\phi)^{dn.}$	10 mm.
as zero								

The horizontal movement of the larynx along the anterior-posterior plane is interesting only in so far as it indicates a change in back cavity formation. For

[1] op. cit. pp. 722-723.

subject 236 as shown in Figs. 101-114 inclusive, it is indicated in the table below. Again the measurements are taken from the position of the anterior-superior corner of the hyoid bone in each case, regardless of any tipping of its plane.

HORIZONTAL MOVEMENTS OF THE LARYNX

French (St. Cloud) Subject 236
Figs. 101-114.

Measurements reckoned from the position of the anterior-superior corner of hyoid bone. (See text).
Position of *a* (âme) (Fig. 109) = 0

	Forward	
y (with lip rounding)...	"	frd. 15 mm.
y (without rounding)....	"	5 mm.
ϕ (with lip rounding)...	"	8 mm.
ϕ (without rounding)....	"	8 mm.
i (si)..................	"	8 mm.
ɪ (lire)................	"	8 mm.
e (blé).................	"	6 mm.
ɛ (bête)................	"	0 mm.
a (semme).............	"	6 mm.
ə (me)	"	1 mm.
ɔ (robe)		bkd. 4 mm.
o (rose)...............	"	frd. 1 mm.
u (rouge)..............	"	frd. 2 mm.

If we combine the horizontal movement figures in a table with the perpendicular in order to show the complete change which resulted in the pharyngeal or

throat cavity, during the French pronunciation of this Parisian subject No. 236 we note the following:

Reckoned from position of *a* (âme)
Fig. 109 as zero.

Effect of larynx movement on pharyngeal cavity dimensions

Vowel	Distension figured from Hyoid			
	Perpendicular	Horizontal	Horiz. decrease	Average increase
y (lip rounded)	8 mm.	15 mm.		23
φ (lip rounded)	10 mm.	8 mm.		18
i (si)	7 mm.	8 mm.		15
i (lire)	8 mm.	8 mm.		16
e (blé)	14 mm.	6 mm.		20
ɛ (bête)	10 mm.	0 mm.		10
a (femme)	0 mm.	6 mm.		6
ə (me)	4 mm.	1 mm.		5
ɔ (robe)	6 mm.	....	...4 mm.	2
o (rose)	4 mm.	1 mm.		5
u (rouge)	15 mm.	2 mm.		17

The conclusion that all parts of the larynx change for each vowel would seem to be confirmed, in so far as they can be observed in these experiments. Whether there is any regularity in the change or not, will have to be determined.

Of course a mere glance at the above table makes it evident that the horizontal and perpendicular movements are more or less independent of each other. In the case of the *ɔ* (in robe) we actually note a perpendicular distension, and a horizontal decrease. And the shift from *y* to *φ* results in an interchange between

the two motions which in each case is diametrically opposed to the other. Yet in the two *i* s, both motions remain almost constant. As stated before, a 1 mm. shift in such an organ as the larynx cannot be considered to have any great importance, so the comparative observation of such a small shift between two vowels is not so vital as the noting of differences between extremes and series. And even these need to be studied in their relationship to other factors with whose function they may be interchangeable.

We have already noted the fact that a constriction of the hyoid muscles attaching to the chin may distend the pharyngeal cavity and alter vowel quality. An examination of Fig. 105 makes it clear that in this *u* at least, the muscles might also so pull on the tongue as to create a material pharyngeal distension in horizontal plane without carrying the larynx or the hyoid bone along with it. For here the base of the tongue at the median line, rests at least a full 8 mm. forward of the anterior-superior corner of the hyoid.

A similar phenomenon can be noted in regard to perpendicular displacement, though it is more manifest in pitch and singing quality changes than in the case of the vowel. For in some of these X-rays a variation of as high as 10 mm. can be observed in the separation between the hyoid bone and thryoid cartilage.

The horizontal narrowing shown in the table for ɔ (in robe) which at the same time is accompanied by the exact opposite in its perpendicular distension, is of more than passing interest. That would seem to point to a decided involvement of surface function rather than that of the cavity.

As the author has pointed out [1] such an elongation of a narrow cavity formed by soft surfaces will inevit-

[1] The author's Speech and Voice in X-ray by Macmillan, containing a more detailed analysis of the evidence and some 200 X-rays extracted from the 3,000 odd the author has taken: English, Spanish, German, Italian, etc.

ably result in a suppression or deadening of the high partials in a complex tone of the type emitted by the vocal cords. The resultant will be heard as a "dead" or "hollow" tone much analogous to that produced by singing into a bung-hole of a barrel, or muffling the tone of a bell by padding its clapper with soft felt. And this constriction of soft surfaces in the throat at that point may be even more important than changes in cavity air volume in accounting for the primary distinction between an *a* and an *ɔ*. At any rate facts noted in this experiment confirm many others already referred to. It will be remembered that some of those which eliminated the mouth cavity in front of this point led the author to agree with Marichelle[1] in the conclusion that so far as the back vowels are concerned the front cavity might be dispensed with.

This does not say that these vowels do not use the lips. It merely points out that they would not be absolutely indispensable, and that these vowels are regularly produced without their involvement. If this is true, it would make the throat cavity and movements of the larynx of prime importance in the production of the back vowels at least; and as has been noted time and again herein, the positions taken for that phayngeal cavity are very vital in changes of front vowel quality. Hence the value of these observations on larynx or hyoid movement must be considered of quite as much importance as the traditional changes in the position of the front tongue, or in other words of the size of the buccal cavity.

That question need not be argued. Since all these vowels are produced on the same glottal pitch, the changes which are so manifest in the tables above given, must have something to do with the vowel. That would be true, if only from the standpoint of the in-

[1] MARICHELLE, La parole d'après le tracé du phonographe (1897) Paris, p. 27.

		Vertical Larynx	Horizontal Larynx			Vertical Larynx	Horizontal Larynx
Humming Closed Mouth, Series I	G	—	—	Series III, 1. a: on G — g	G	+ 2.00	— 1.25
	A	+ 3.25	— 1.25		A	+ 1.50	— 1.00
	B	+ 5.25	— 1.00		B	— 2.50	— 1.25
	c	+ 1.00	— 1.25		c	— 2.00	— 0.50
	d	— 2.50	— 0.25		d	— 5.00	— 1.25
	e	— 7.00	+ 1.75		e	— 1.25	— 0.25
	f	— 7.00	+ 1.00		f	—	—
	g	— 7.00	+ 2.00		g	— 7.00	+ 1.00
Series II	G	+ 7.75	0.00	2. Sung on G	u:	+ 14.00	— 6.00
	A	+ 2.75	+ 0.25		o:	+ 10.25	— 4.50
	B	+ 4.00	0.00		ɔ	+ 6.00	— 4.75
	c	+ 2.75	0.00		ɑ	+ 0.50	— 4.50
	d	— 3.00	+ 0.25		a:	+ 2.00	— 2.00
	e	—	—		ɛ	+ 1.00	— 2.50
	f	— 5.50	+ 2.50		e:	0.00	— 0.25
	g	— 4.75	+ 0.25		i:	+ 3.50	— 3.00
	a	— 4.00	+ 2.50				
	b	—	—				
	c¹	— 7.50	+ 7.00	3. Whispered Vowels	u:	— 2.50	— 0.50
					o:	—	—
					ɔ	+ 1.50	— 2.50
					ɑ	— 2.50	— 1.50
					a:	— 2.00	— 3.00
					ɛ	+ 4.50	— 3.25
					e:	—	—
					i:	—	—

Eijkman's Measurements on Larynx Position made from X-rays

fluence which distension and contraction have on changes in the resonance capacity of the cavities. And as Sir Richard Paget has shown, the front buccal cavity with its openings might be kept at exactly the same dimensions and yet its natural resonance period be radically altered by coupling on back resonators of varying capacities.

Of course there might be other reasons for these physiological shifts manifest in the position of the Hyoid and Thryoid as tabulated and noted above — others which our present state of knowledge makes it impossible to understand. But that does not do away with the importance of the facts just mentioned. So we reiterate that these movements are so radical they must of necessity have quite as much influence on vowel quality as do changes in the resonance cavity caused by shifts in front tongue position. And it cannot but be considered unfortunate that the tongue-arching vowel triangle should have led us to all but disregard them and concentrate our attention on the front buccal cavity. The author has shown herein, that the fantastic symmetry postulated in that triangle is chimerical. These X-rays make it evident that many compensatory physiological changes are regularly taking place, and we might just as well give up the idea of trying to pigeon-hole any one set of physiological vowel facts and forcing them to conform to one single ordered symmetrical explanation of vowel quality differences. And so whether some of these theoretical phoneticians like it or not, the author, in order to be scientifically accurate, is forced to drop this consideration right there. For that is the conclusion this chapter has to draw, viz.:

The radical shifts in the different vowel positions of the Thryoid cartilage and Hyoid Bone, being as they

are, largely responsible for varying alterations in the pharyngeal cavity and interior larynx, must be considered of quite as much importance as changes in the front buccal cavity, through shifts in the tongue and lip position. But there is no more uniformity manifest than in tongue position. And this must of necessity be true, for a variation in one function, could easily be leveled out through a compensation coming from another — **in the normal human individual the ear is the controlling guide.** And for that reason the author again takes this opportunity to urge the return to an acoustic scheme for ordering vowels in preference to the present physiological tongue-arching triangle. But if physiological it must be, the position of the Larynx and Epiglottis, as well as Lips and Tongue, cannot be left out of consideration. And as has been suggested in Chapter 13 if the scheme must be triangular that most commonly used about the beginning of the last century, with the *a* (ah) turned to the side, more nearly fits the broader physiological as well as acoustic facts.

CHAPTER X

TONGUE-ARCHING VOWEL TRIANGLE — A FALLACY

> "Even though for the highest vowels **i** and **u**" (of the vowel triangle) "— but hardly for the rounded **y** — the highest point of tongue arching may be fixed with a certain amount of verisimilitude, nevertheless the justifiableness becomes less and less; the farther the tongue gets away from the palate in the direction of its lower artification . . .
>
> "But taking it for granted that a highest point of tongue articulation could be indicated with exactness for every vowel, even then the indication would remain incomplete since the amount of arching of all other points along the middle line of the tongue are certainly not without bearing as characteristics of the tongue articulation for a sound . . .
>
> "Meyer has published a large number of tongue positions obtained by his plastographic method . . . which **prove all of our former conceptions in regard to tongue articulation to have been erroneous.**"[1]
>
> — Viëtor 1914.

This statement from Viëtor will probably astound more than one scholar who has come to accept the present vowel triangle as firmly established in fact. For Viëtor may be considered the father of the physiological triangle now so widely used. In his prolific

[1] VIETOR, Wilhelm. *Zur Systematik der Vokalartikulation,* in Miscellanea Phonetica, 1914, "Le Maître Phonétique 23 Jubilee publication of the I. P. A. Italics and material in parentheses mine.

writings, and as one of the most influential linguistic scholars and teacher of scholars, he vigorously urged and defended this scheme. And so successful was he and those who supported the same view, that it finally came to almost supplant all others.

Now he comes forward with the statement that the tongue does not arch as the vowel triangle he urged, postulated it did. And in the above quotation he closes with the definite assertion that scientific experiments

> "prove all of our former conceptions in regard to tongue articulation to have been erroneous."

In thus renouncing one of his most cherished views, he shows himself to be a real scholar, for he could well have been excused for defending his own scheme to the last and so long as it had any supporters. But instead, he frankly acknowledged its error, and that while many of those in his field less qualified than he remain oblivious to modern scientific evidence and still cling tenaciously to the shell long after it has been exploded.

While Viëtor's admission is of more than usual significance because of his relationship to the development of the present triangle, yet he is not the only one to note the import of recent investigations. Some of its most tenacious supporters have brought about modifications, in an attempt to make it at least conform outwardly with what experiment has shown to be inescapable physiological fact; at least with some of those which would be apparent to the merest novice. Such is the modification in the form now published by the International Phonetic Association, in which the line for the front series of vowels is made to drop perpendicularly instead of slope back from the alveolar ridge. The earlier truncation, was also apparently designed to meet some similar defect in the purely

triangular scheme. The provision for representing rounding was likewise.

But let us return to the triangle as such. We said above that others had noted the failure of scientific investigation to support its physiological postulates. As a matter of fact, the author has been frankly surprised to discover how few real phoneticians there were who actually ever did support it as an authentic representation of the full physiological causes of vowel quality differences.

At least the scientific phoneticians avoided its use, or were careful to say that it was merely a convenient mnemonic device. That was Grandgent's attitude. Weeks never believed in it. Jespersen much preferred other schemes and early advanced more than one cogent reason for substituting something which would be more accurate. The same thing might be said of Sievers. Ellis preferred the earlier device of du Bois-Reymond in that case where he felt the necessity of using any at all. Sweet and most of his students followed Bell in the usage of his quadrangular box. Czlumsky, Grammont, Marage, Poirot, and a host of others were too busy with real studies in phonetics to waste any time with it. And the Abbé Rousselot was absolutely set against it, as well he might be, if one may judge by his experiments which bear on this subject.

All the evidence Rousselot was able to accumulate disproved, rather than sustained the idea involved in the vowel triangle. Take for example, his palatograms shown on pages 651, 2, and 653, et seq. A glance at those on page 651 will show that no vowel there has a tongue-arching articulation which is at all alike for any two subjects. If we compare his palatogram for the vowels of subject No. 6, with that for those of

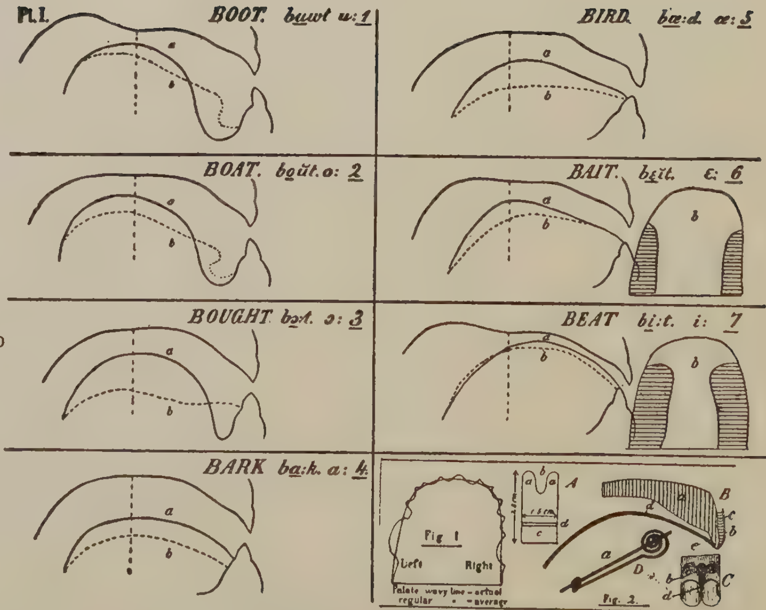
SERIES 1.

FIG. 54 FIG. 51

FIG. 53 FIG. 50

FIG. 52b FIG. 49

FIG. 52



ATKINSON'S VOWEL DIAGRAMS

No. 8, we are immediately struck by the fact that No. 6's tongue-arching for *i* (which the Abbé marks with line numbered 8) takes place considearably farther back than Subject No. 8's does for *a*.

And the arching on *e* (marked by the Abbé on the

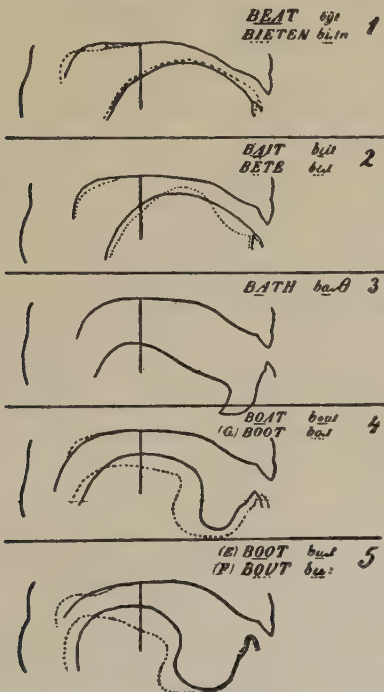


FIG. 59

FIG. 58

FIG. 57

FIG. 56

FIG. 55

ATKINSON'S VOWEL DIAGRAMS

palatogram with a "5") for either No. 6 or No. 7, page 651, takes place still farther back and down. There is then actually shown a front cavity more *"closed"* for this *e* than for the *u* of subjects Nos. 1, 2, 3, or 4, on page 653 (Note that he has indicated the latter with "x..x..x.." line "6").[1]

[1] ROUSSELOT, L'Abbé P. J. Principes de Phonétique Expérimentale last ed. Didier, Paris. p. 651, et seq.

These palatogram experiments of the Abbé Rousselot's are of particular significance. First because he began to publish them at a very early date, (that is relative to the appearance of our present tongue-arching triangle which for that reason makes it surprising that supporters of the scheme did not pay more attention to the evidence which was there and merely needed application.) And second, because he is about the only one who has made a really scientific check possible; by tracing accurately and without any attempt to force results to conform to a given theory; and publishing palatograms for more than one subject in a given language.

It is true that since these palatograms gave cross-section views one had to build the median section by resort to analogy. And that fact might readily have been advanced against the experiments where so applied; for the Vowel Triangle is supposed to portray the perpendicular movements of the tongue, rather than the lateral. But nobody seems to have seriously urged such a protest.

As a matter of fact it has been a very common thing for phoneticians who utilized palatograms to construct purely imaginary side view profile tongue positions based on the theory of an analogous relationship between the cross section and median position. And since they usually presented these without explaining that they were imaginary many a scholar unversed in the processes of scientific phonetics, jumped at the conclusion that the side view was also registered by experimental means. When the author first presented the X-ray experiments herein to his distinguished friend and fellow countryman, Dr. Aurelio Espinosa of Leland Stanford University, the latter was inclined to argue that they must be wrong because they did not

agree with the side-view tongue profile positions published by Tomás Navarro Tomás in his Pronunciación Española; and since this work follows the tradition and fails to state that the side views are purely imaginary tracings based on the more or less conventionalized palatograms which accompany them, the author was unable to convince his friend. That was in the Autumn of 1924. A visit made at the same time to the University of California resulted in a similar expression of views. The large part of a whole day spent in explaining the technique which the author had developed after several years of arduous labor, and the differences in processes used, failed to entirely convince some of his friends there. Since that time Prof. Holbrook, among those present to whom he explained his process, has obtained a set or two of X-ray vowel tongue positions which he writes "may show clearly enough to be of service." Perhaps their publication may carry greater conviction, for we may be sure they will fail to conform to the tongue-arching triangle's positions, postulates and theories. At the M. L. A. meeting in New York (Dec. 1924) the author read his paper on "The Vowel Triangle — a Fallacy" and after the meeting encountered similar objections, coming mostly from philologists and others unacquainted with the processes of scientific phonetics. Most of these were also prone to cite the median section imaginary diagrams in such works as that above mentioned as evidence against the validity of the X-rays, never realizing that the former represented a product of pure imagination or at best doubtful analogical reconstruction, whereas the X-ray presented the exact tongue position as it was during the production of each given vowel. The only other apparently valid objection they urged, was really without foundation since it was

against the masking process the author used in order to make the negative more readily readable by the uninitiated, and the outlining utilized in order to preserve in the half-tone, details clearly shown in the negative, but which otherwise would surely be lost in printing. The author has had no desire to falsify his record, and that is the implication contained in such an objection; but in order to meet that objection he has seen fit to publish herein, the stereographic set, which appearing as it does in duplicate, makes it possible to accentuate the outline in one and leave the other untouched. And no masking whatever is utilized. Yet the reader will observe that in every detail, this set of experiments confirms the general conclusions to be drawn from the others, published for the most part in the author's "Speech and Voice" (Macmillan). So that objection is also shown to be without foundation.

Blame cannot of course attach to the older conservatives who cling tenaciously to the triangle and other schemes they have so long used, even though without thot as to validity. And it is perfectly natural that they should seek to bolster their position by any such citations, which have been thot to represent actual evidence. But so far as such profiles are concerned, one who knows their manner of construction, would be anything but scientific if he cited them as evidence opposed to X-rays. For the palatogram shows the contact made by the edges of the tongue against the roof of the mouth. Does that indicate how high the center arches, when as we know, those edges may curl up **concave-like**, and then be much higher than the center; or the median line of the tongue may arch up in the center higher than the edges **convex-like**; or one part of the tongue may show concave, and the other convex; and comparatively, the whole picture may be

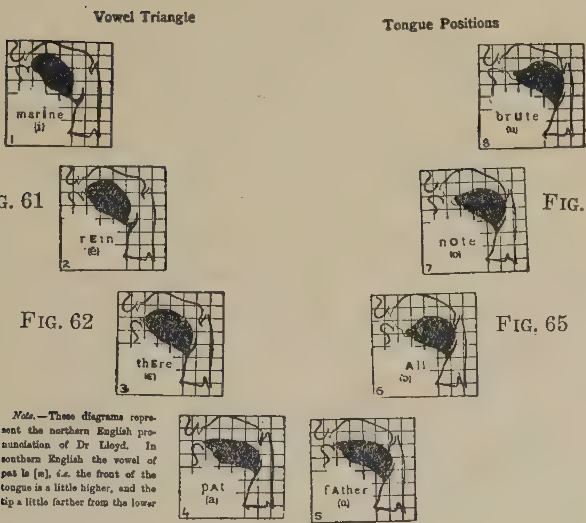


FIG. 60 FIG. 61 FIG. 62 FIG. 63 FIG. 64 FIG. 65 FIG. 66 FIG. 67

Note.—These diagrams represent the northern English pronunciation of Dr Lloyd. In southern English the vowel of pat is [æ], *i.e.* the front of the tongue is a little higher, and the tip a little farther from the lower

FIGS. 60 to 67

These are the traditional tongue positions postulated by the vowel triangle. A comparison with what the X-ray shows as facts will make it evident that they are highly fantastic. Too many so-called "phoneticians" especially among those who called themselves "practical phoneticians" have accepted them as facts rather than for what they are — **pure fictions of the imagination,** purposely constructed to fit a theory. That is the reason we see the little short cavity for *i* Fig. 60 and a progressively longer and wider one as we progress thru the series to *u* Fig. 67 — a beautifully symmetrical scheme as long as the facts are of no importance, and the imagination is given free play.

vitally altered by the different types of palates which vary as much as do faces? How foolish to advance such profiles as evidence! The palatograms show cross sections, covering only the **narrow** and **wide** theories, and that merely in so far as they pertain to the palatal, or front buccal cavity. As stated above, such of those published as were actual record of experiments, rather than conventionalized imaginary tracings, stand as evidence against the tongue-arching triangle.

To that group, the author adds herein, what is perhaps the largest published collection, thus far made on unbiased or uninfluenced subjects. See Figs. 301 to 539. They are all reduced by just one-half and so that the reader can make his own measurements. Since the reduction factor is kept constant he can also make comparisons of one with another. One who can find in them, such uniformity as to sustain the tongue-arching triangle postulate will provide us with a distinct surprise. In order that the author's preconceived notions might not enter in, they were made by others; but where they manifested surprising peculiarities as in Figs. 439 and 441, three of us checked them carefully so as to be sure they represented the individual's normal vowel position; and so whether peculiar and unexpected or not, they have been given in order to present an absolutely faithful and uncolored record. Palatograms of that type, and of the kind published by the Abbé Rousselot, provide us with a valuable record, and are not open to serious objection. The objection is to be urged against their misuse in postulating therefrom median or profile tongue positoins, especially when the latter are extended on the basis of pure imagination past the palatal so as to portray the pharyngeal and velar positions.

An actual median record was obtained by Atkinson,

copies of whose positions are shown in Figs. 49 to 59. These too are open to the same last objection above cited.

The same thing might be said of those obtained by Lloyd, and republished by Ripman, or more recently by Crandall. They were diagrams built to conform to a theory and do not present an actual record of facts. They are given herein in Figs. 60 to 67

The results obtained by Grandgent are far more accurate, and represent the finest work done in those days of meagre experimental facilities. They are shown in Figs. 68 to 100. But of course they necessarily had to be a composite rather than a single enunciation, being obtained by finger and given diameter disks used to make measurements at various points.

The development of Meyer's plastographic method, however, was not open to any such objection; for it was devised for the purpose of indicating the perpendicular position of the tongue along the median line; and this should have shown precisely the same thing the vowel triangle was supposed to represent. Meyer's experiments also ran directly contrary to the conceptions involved in the triangular scheme, as Viëtor indicated in the quotation at the beginning of this chapter; and anybody who sought evidence in favor of the triangle in these painstaking experiments would be doomed to sore disappointment.[1]

Meyer's X-rays[1] confirmed the results shown by his plastographic studies.

The X-ray photographs of tongue positions for various vowels, as published by both Scheier[2] and Barth,[3]

[1] MEYER, E. A. *Untersuchungen über Lautbildung.* Viëtor Festschrift, Elwert, 1910, Marburg. p. 172.

[2] SCHEIER, M. *Bedeutung d. Röntgenverf.* etc. Arch. Laryng. Bd. 22, H.2, p. 175.

[3] Barth, E. and E. Grunmach, *Röntgenographische Beiträge z. Stimmphysiol.* Arch. f. Laryngologie, Bd. 19, p. 396-407.

(see tracings made from the latter, Figs. 23-31 herein) also show conclusively that the tongue-arching triangle we have been using is fallacious. They were of course not interested in either proving or disproving this scheme with its vowel theory implications, and so they make no attempt to apply their findings to its interpretation. But it will take no technical expert to see how far the tongue positions they show are, from conforming to the triangle. They confirm the results shown not only in the author's present study, but those in his other X-ray study "Speech and Voice" published by Macmillan; and surely no one can examine these X-rays (which give the tongue position of such a large number of subjects showing little agreement with the scheme), and still maintain he finds substantial proof in favor of the triangle conception.

That about sums up the real evidence which bears on the question before us. We shall deal more in detail, with the specific facts shown by the above authors in regard to position and openings, in the chapter on "open" and "closed" vowels. Here it will suffice to say that such experiments as have been carefully performed to show the actual tongue positions required in order to produce vowels, disprove rather than prove, the Vowel Triangle Theory; and it stands practically unsupported by any real scientific experiments devised to show tongue movements and tongue position. Those of us who accepted it as a thoroughly reliable scheme and theory may be pardoned for expressing regret that scientific investigation has not substantiated its authenticity. The author must admit that it was with somewhat of a pang that he was first brought to a realization of the fact that the evidence in its favor, which he sought for the benefit of his own students when he first began these X-ray experiments proved

rather to be opposed. Such are the facts, however — and there is nothing to be gained from either suppressing the facts, or in playing the ostrich and trying to hide from them.

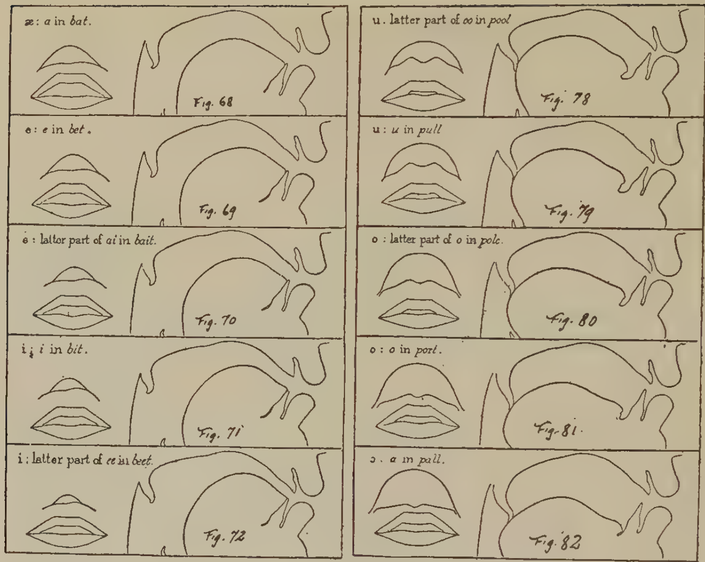
Perhaps it may not be amiss for us to pause now for a moment in order to analyze the scheme which is thus opposed.

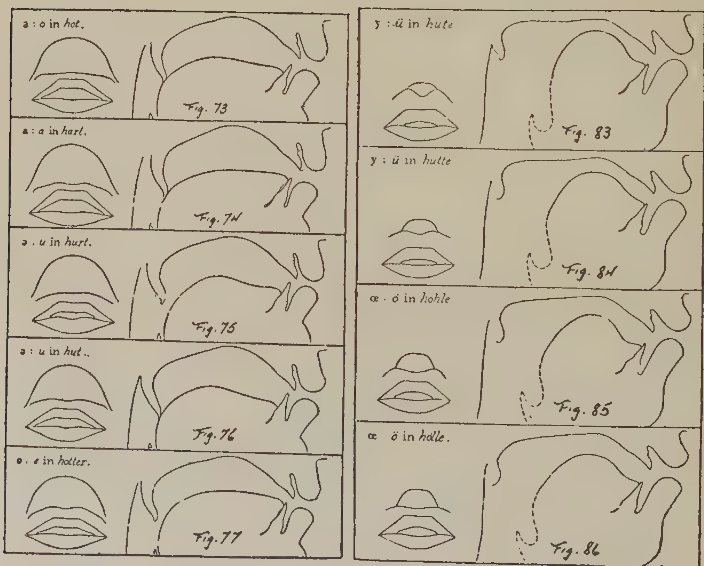
Our modern tongue-arching vowel triangle conceives of vowel quality as being due to a progressive change in the point where the tongue bunches. It is commonly represented as in Lloyd's Vowel Chart.[1]

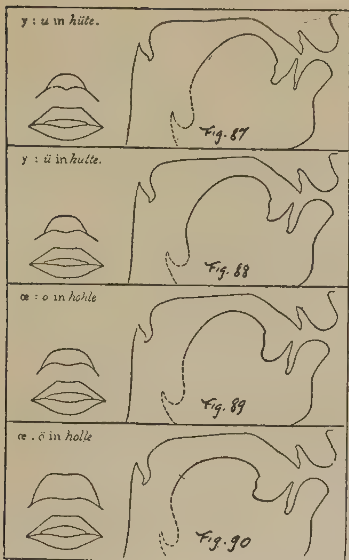
Generally speaking, the back cavity and function of the epiglottis is either disregarded or else thot by language teachers, philologists, and other linguistic scholars to be absolutely unimportant. It is the position of buccal tongue-arching which is constantly referred to. On the whole this is not considered in relationship to any changes in resonance which it might create in both the primary cavities. There is almost an entire lack of any such comment. So while his charts are used, Lloyd's whole theory of double resonance seems to have been forgotten. This is perhaps largely due to the lack among them of a sufficient background in the scientific foundations of phonetics which leads them to think of the laws of resonance in their relationship to two or more vocal cavities as something more complicated than it really is. Hence the general tendency is to simplify even Lloyd's simple scheme, and limit consideration to mere point of tongue arching in the front cavity alone.

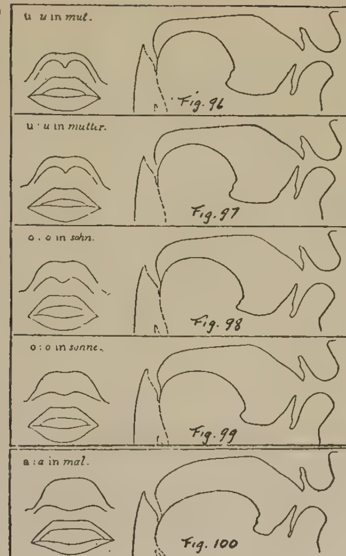
This modern scheme is generally interpreted by saying that the vowel quality changes in regular stages, as the tongue arches progressively farther down and

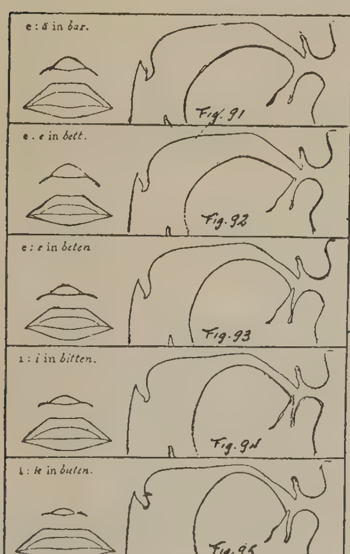
[1] LLOYD, *Speech Sounds: their nature and causation.* Proc. Lit. Phil. Soc. Liverpool, 1890. (Doctor's thesis.)


æ: a in bat.
Fig. 68
e: e in bet.
Fig. 69
e : latter part of ai in bait.
Fig. 70
i : i in bit.
Fig. 71
i : latter part of ee in beet.
Fig. 72
u. latter part of oo in pool
Fig. 78
u : u in pull
Fig. 79
o : latter part of o in pole.
Fig. 80
o : o in port.
Fig. 81
ɔ . a in pall.
Fig. 82


a : o in hot.
Fig. 73
a : a in hart.
Fig. 74
ə . u in hurt.
Fig. 75
ʌ : u in hut.
Fig. 76
ə . e in hotter.
Fig. 77
y : ü in hüte
Fig. 83
y : ü in hütte
Fig. 84
œ · ö in höhle
Fig. 85
œ ö in hölle.
Fig. 86







GRANDGENT'S
VOWEL POSITIONS

The earliest really experimental determination of positions taken in vowel production. Ascertained with the finger, and disks of varying diameter. As the reader will note these positions are by far the most accurate of those made before the X-ray. That can be seen in the position for the pharyngeal cavity. This is quite remarkable in view of the meagre means available at that early date for such examination.

farther back. Where Bell's terminology of "high, mid, low; front mixed back" is added to it[1] we get the following triangular scheme:[2]

eel	1	hf	hb	17	pool
ill	2	hf	hb	16	pull
ale	3	mf	mb	15	old
air	4	mf	mb	14	ore
ell	5	lf	lb	13	all
an	6	lf	lb	12	doll
a	7	mx	mb	11	up
ask	8	mb	lx	10	err
	ah	9	lb		

Or, if you reduce it to the group of vowels given by Rippmann,[3] it will show as follows:

i	*u*
e	*o*
ɛ	ɔ
æ	*a*

As cited by him, using Lloyd's diagrams for the purpose, Ripman shows the interpretation as it is now almost universally given. The tongue bunches well up toward the alveolar ridge for *i;* a little farther down and back for *e*; farther still for ɛ; flat for *æ*; then flat again for *a,* but beginning to arch up towards the uvula; a pulling in of the tongue tip and an arching a little farther back and up for ɔ; more still for *o*; and a maximum arching up and back towards the uvula for *u.*

That was the simplicity which captivated the minds of its users. It was not uncommon to find individuals who considered themselves "full-fledged phoneticians"

[1] BELL, *Essays and Postscripts* (1849) p. 31,
Sounds and their Relations (1886) p. 63.

[2] As given by VIETOR, Elemente der Phonetik, 6th Ed. Reisland, 1915. p. 60.

[3] RIPPMANN, Walter. *Elements of Phonetics,* 7th Ed. Dutton 1918, p. 28.

when they were able to use a phonetic alphabet and this triangle. Yet there was never any scientific evidence adduced in its favor, and such objective studies as we had of the interior cavities, tongue position and contact, tended rather to disprove it.

What are the facts? An X-ray examination shows many which cannot be reconciled with the Vowel Triangle theory. All X-ray photographs thus far published show how fallacious it is in its fundamental postulates. Meyer, Scheier, and Barth, et al. agree with those herein, and so there can be no question but what the theory itself is in error.

If the reader will turn to the stereographic set of X-rays published herewith, he will note:

First, that it is only by the biggest stretch of the imagination that we can make out anything which at all resembles points of tongue arching which would remotely correspond to even the three extremities of the triangle, $^{u}\ _{a}\ ^{i}$

Second, the front vowels do not arch against the alveolar ridge, and drop off towards the back from that point. Hence Sweet's statement is not true when he lays the foundation for that phase of the triangle postulate, in a fallacious explanation;[1]

> "*I* owes its high pitch to its being formed by a very narrow, short passage in the front of the mouth,"

for while it is true that the pitch of an organ pipe is dependent on its length, and almost uninfluenced by its diameter, that law cannot be the one which operates to produce vowel quality in the mouth. And that leads us to another point, viz.

Third, that the tongue arching for front vowels actu-

[1] SWEET, Henry. *The Sounds of English,* (1910) Oxford Press, 2nd ld. p. 31.

ally extends back to the soft palate,[1] as far as the articulatory point for a *K*. (This observation has vital bearing on the current explanation used to account for the *K* plus yod palatalization.[2])

Fourth, that in this subject, at least, the point of arching for the *u* is not much farther back than is that for the front vowels.

Fifth, that the length of that cavity is almost identical, and the point of tongue arching is not essentially farther back for one or the other of the front vowels; i, *I*, *e*, ɛ.

Sixth, that there is no such consistently regular or progressive perpendicular opening of the front cavity, as is postulated in the Vowel Triangle. The *e* may be more closed than the *ɪ*; or the *ɪ* may turn out at times to be even more open than the *æ;* and it is actually possible to produce an *i* with a front cavity which is more open than that for an *e*.

*   *   *   *

Seventh, there is little relationship between the back vowel positions shown in this stereographic set of X-rays and those postulated in the vowel triangle. The point of arching for the *e*, *a*, *ɔ*, and *o*, is not against the velum or upper throat at all, but rather towards the back throat, or posterior wall of the pharynx, down by the epiglottis.

Eighth, so far as tongue position is concerned, the

[1] If the perpendicular drop for the front leg of the present I. P. A. triangle is meant to correspond to that velar point in the mouth where the tongue is now known to arch in front vowels, it breaks into the whole theory of the vowel triangle, and represents a distorted physiological scheme without physical fact to support it. Would it not be better to discard entirely the physiological scheme and terminology, and revert to more reliable acoustic factors?

[2] MEYER-LUBKE, W. *Romanische Sprachwissenschaft*, 3rd ed. Heidelberg 1920, pp. 163, 164, etc.

u of this subject has more in common with the *i, ɪ, e, ɛ*, series than with the *a, ɔ, o*, series. But this is not always true, for individuals show variation in the tongue positions taken, for this back group in particular, which is almost as great as the differences between their facial features. That is one of the most outstanding reasons why the physiological vowel triangle must be considered unreliable, and without value.

Ninth, many of the back vowels may take almost any front buccal position imaginable, and still manifest perfectly good quality. The reader may prove that fact for himself, if he will press the tongue tightly against the roof of the mouth and say "too........!" (*u*), or "bah........" (*a*). Where the tip, or whole front part of the tongue is placed, would for that matter, seem to be of no importance whatever. That is easily noted in a wide variety of forced positions in which we can place the front tongue for the pronunciation of "bah, baw, bow, boo" (*a, ɔ, o, u*).

Tenth, a constriction of the throat cavity down in the neighborhood of the epiglottis seems to be characteristic of the *a* series of vowels. But it is not progressive as the vowel triangle would make it. Nor is the relativity constant for all individuals, or as between them.[1]

In this stereographic series, the opening varies from narrowest for *ɔ* (aw), thru *a* (ah), *o* (oh), *æ* (at), *u* (oo), to *ə* (uh) as the most distended of the cavities at that point. The *ɔ* (aw), *a* (ah), and *æ* (at), are the only three which always maintain a constriction at that point in all subjects thus far examined. Hence it may be said that there may be a possibility of this epiglottal opening partially conditioning their quality. If that is true, then the older physiological vowel tri-

[1] The lips may possibly compensate and cause considerable variation.

angle is far more reliable than the one we now use. This older one, which was in vogue at the beginning of the last century, would have placed the *a* in the throat at the left, the *i* against the hard palate at the upper right, with the *u* at the lips in the lower left front; thus

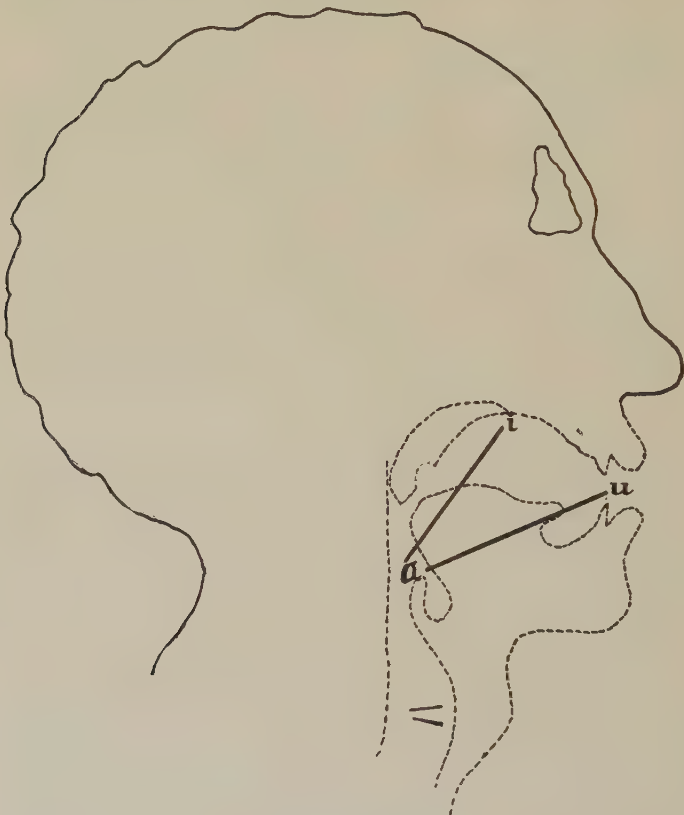


FIG. 100-b
The Old Vowel Triangle
as in vogue at the beginning of the last century (sometimes credited to Orchel), and the one which modern X-ray experiments most nearly sustain.

The vowels between *a* and *i* (such as *æ* ɛ, *e*, and ɪ) would in its interpretation be due to a mixture of the pharyngeal and hard palate quality differences; and those between *a* and *u* (including ɔ, *o*, etc.) to a mixture of the pharyngeal and lip quality differences. Some may see justification for retention of such a physiological triangle, but so far as the author is concerned he would much prefer to stick to known facts. And these facts deal with the acoustic quality. These we can consider in later chapters. For the time being it should suffice to warn against any move tending to base classification on uncertain physiological factors, which are widely variant and of unknown influence.

One of the most striking departures from the traditional vowel-triangle tongue position, is shown generally by the X-ray pictures of *æ*. The triangle would have made the tongue lie flat as in Ripman's lower left diagram, yet the X-ray usually shows it with a decided hump.

As a matter of fact in ordinary speech the *æ* rarely, if ever, takes a flat position. Not that it could not, and still retain its quality. It gave the author a distinct shock to discover that well trained *singers can sing* on a loud swelling note *almost any* of these *front vowels with the tongue relatively flat in the mouth.* Most vocal teachers would confirm this statement, and as a matter of fact, the majority of them spend considerable time in training the student to "keep the tongue out of the way" by so producing them. At least it may be said that the tongue position looks flat when observed from in front through the mouth opening. But when we look at it from the side, as it is seen in these X-ray pictures, the impression may be quite different in consequence of our side view, rather

than a front one through the mouth which hides the arch. By looking into the mouth of a tunnel we can never tell what the shape is beyond a certain point in the dark recesses.

Now of course this hump in the center of the tongue for æ, as in Figs. 167, 179 and 192 of the author's "Speech and Voice," is not absolutely essential. It is always dangerous to draw conclusions as to the essential, from what appears to be evident, without the test of a counter experiment. Failure to do so is as bad as basing a theory on too few facts. In this case we know that we may force the tongue down with the finger and produce an easily distinguishable *æ*, ɛ, *e*, or even *ɪ*. Of course our speech habits, trained through the years, struggle against it, and it is interesting to observe the force with which the tongue opposes this attempt. One who tries it and senses the power the tongue exerts in the attempt to take its normal position will not take too seriously the objection of Scheier's[2] which he urged against Meyer's use of little lead plates as a marker. They weighed 0.05 g. each, and 13 of them can be counted in one of his X-rays published in the Festschrift[1]— that for *o*. Comment has been made elsewhere herein on an actual test made of the effect such an infinitesimal weight on the tongue may have on the quality of the vowel.[4]

As indicated above, both these experiments of Meyer,[1] and those of Scheier[2] and Barth[3] show con-

[1] MEYER, *Untersuchungen über Lautbildung.* Viëtor Festschrift Elwere, 1910, Marburg I. H. p. 172.

[2] SCHEIER, M. *Bedeutung d. Röntgenverf.* etc. Arch. Laryng. Bd. 22, H.2, p. 175.

[3] BARTH, E. and E. GRUNMACH, *Röntgenographische Beiträge* zur *Stimmphysiologie*, Arch. f. Laryngologie, Bd. 19, p. 396-407.

[4] The author takes this opportunity to object to such condemnations based merely on vague feeling, and somebody's statement used as a lazy means of avoiding an experiment which would prove or disprove the contention.

clusively that the tongue-arching triangle we have been using is fallacious. The X-rays reported herein confirm their results in this respect. These also agree with what Viëtor commented upon[1] as being present in Meyer's plastographs, when he found *I* to be more "open" than *e*, and as between certain languages finds the *e* to be more "closed" than *i*. This need not be ascribed to the fact that those experiments were dealing with different languages. If that were true it would mean that the southern Englishman, or north German would be constantly hearing *e* when the Italian used *i*. That is, if the Italian said *"si"* they would be hearing *"se."* Our X-rays show that in the same subject, the *I* is very often more "open" than *e*.[2] As a matter of fact, *I* is often more "open" than ε.[3] In some cases *I* is actually more "open" than *æ*, all in the pronunciation of exactly the same individual.[4] And so far as the back vowels are concerned, there is an even more shocking lack of conformity with our conceptions of "open" and closed" vowels. The tongue may lie absolutely flat in the mouth for all vowels from *a* to *u*.

It may be said, therefore, without fear of contradiction from any thoroughgoing experimental investigation, that our physiological triangle conception of vowels is erroneous. Yet that there is an acoustic difference is undeniable. Knowing these facts, would it not be wiser to use an acoustic scheme to represent them?

The physiological vowel triangle fails to represent

[1] VIETOR, Miscellanea Phonetica: Association Phonétique, as before.

[2] Compare Figs. 164 and 165; 175 with 176 and 178; 189 with 190; etc., of the author's Speech and Voice.

[3] See Fig. 175 compared with 177; or 189 with 191.

[4] Compare Fig. 175 with 179.

any aspect of the scientific facts. Hence for philological work it must inevitably lead us into numerous difficulties of interpretation which would actually not be existent.

Then as a teaching medium, since it is seriously defective, it could doubtless be replaced by some more efficient scheme. Some of these we can consider in another chapter.

CHAPTER XI

MOUTH CAVITIES — COMPUTED VOLUMES

Vowel Quality Not Caused by Mere Volume of Air

"The natural period of a resonator depends on its volume. The shape of the cavity is of little influence. The size and shape of the opening are of great effect. . .
"The resonance period of the mouth in speech probably depends mainly on the size of the cavity and on the size and shape of the labial, lingual and nasal apertures."
— Scripture (1902) [1]

"In the organ of voice, the reed is formed by the vocal chords, and associated with this reed is the resonant cavity of the mouth, which can so alter its shape as to resound, at will, either to the fundamental tone of the vocal chords or to any of their overtones. With the aid of the mouth, therefore, we can mix together the fundamental tone and the overtones of the voice in different proportions. Different vowel sounds are due to different admixtures of this kind."
— Tyndall (1875) [2]

"The investigation of the resonance of the cavity of the mouth is of great importance. The easiest and surest method of finding the tones to which the air in the oral cavity is tuned for the different shapes it assumes in the production of vowels, is that which is used for glass bottles and other spaces filled with air. That is tuning forks . . . have to be . . . held before the opening . . . the

[1] SCRIPTURE, E. W. *Elements of Experimental Phonetics.* Yale Anniversary Series (1902). Scribners, N. Y., p. 14.
[2] TYNDALL, John. *Sound* (1901). P. F. Collier and Son. p. 242.

> louder . . . heard, the nearer does it correspond with one of the proper tones of the included mass of air. Since the shape of the oral cavity can be altered at pleasure . . . we thus easily discover what shape the mouth must assume for its included mass of air to be tuned to a determinate pitch."
> — Helmholtz (1870)

> "As it was important for my phonetic researches I have made many attempts to determine my own vowel resonances, but have hitherto failed in all my attempts.
> — Ellis (in his note to above).[1]

All basic or cavity tone theories used to explain vowel quality differences, have generally based their postulates on the supposed influence of the total volume of air contained in the vocal cavities. Two of the most important of those theories are represented in the Wheatstone-Helmholtz, and Hermann-Scripture, the harmonic and inharmonic, respectively. For that reason this chapter has been begun with quotations from each.

As previously indicated, the X-ray experiments for the present investigation, were so controlled as to provide pictures of the vowel cavity in median section or point of widest opening in a perpendicular cut of its whole length. It was not possible to obtain for publication, a cross-section record which would give the same completely sweeping view at a glance; but the author's laryngo-periskop provided with a measuring scale, made it possible to obtain the record for the pharyngeal or back cavities; and the already well known palatographic method of the Abbé Rousselot gave that of the front cavity simultaneously with that of the others. Hence it became possible to obtain the

[1] HELMHOLTZ, H. L. F.; ELLIS, A. J., annotated 4th ed. (1912) *Sensations of Tone*. Longmans Green and Co., N. Y., pp. 104, 105.

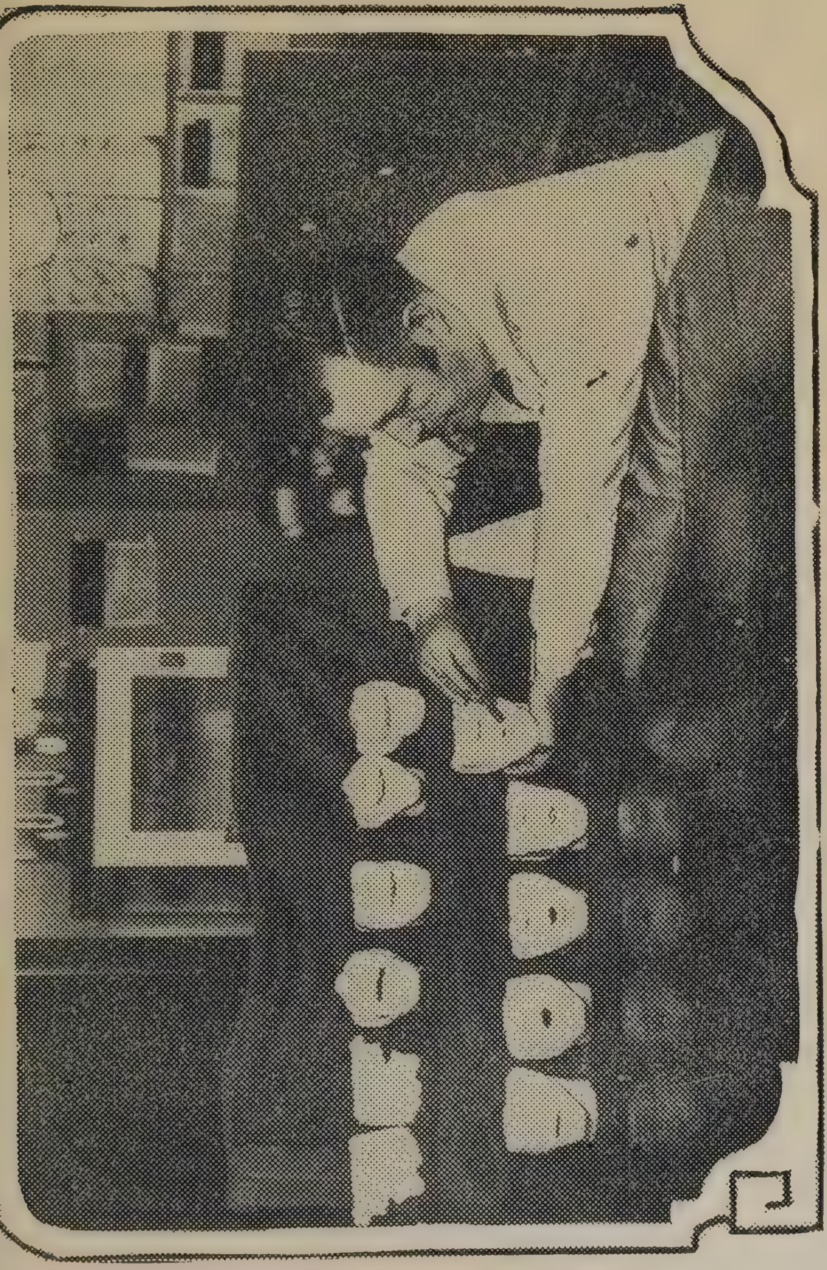


FIG. 100-c. Reproduction of Subject 291's exact vowel cavities fails to reproduce the vowel.

dimension of those cavities in three planes. And having the three dimensions, we are able to reconstruct the cavities, as they were during the production of any given vowel.

Such a reconstruction in clay was undertaken of the cavities utilized by Subject 291, based on the exact dimensions manifest in each vowel at the time of its production. Since these were accurate to a millimeter, it follows that once the cavity was complete, the openings, form, and total volume of air would be exactly the same as those manifest in the human vowel cavities of this girl.

If the volume of air functioning as a resonator were alone responsible for the vowel quality, it should therefore be possible to add a glottal note and reproduce a perfectly good voiced vowel, which would closely resemble that of the young lady. To that end, we added an artificial glottis made from a freely vibrating reed, of the same pitch as the voiced note she used for the production of the vowel when we photographed it. This glottis was inserted at the exact point in the larynx provided in the model which the X-ray showed would correspond thereto. But disappointing as it was, the author must in all honesty, acknowledge that the result had practically no resemblance to the vowel it was supposed to represent. Of course he is not referring to the fact that he might not convince himself that he heard a corresponding vowel quality; nor that he could not have so conducted the experiment as to place those who were listening in that psychological attitude of mind, or "set" which would make them nod their heads and say "yes that is right." Unfortunately this has been the customary process in artificial reproduction of vowels. But to make the experiment scientific it must be more carefully conducted than that.

To show the facts, a large number of observers were placed (at various times) at a hearing tube hook-up and set to recording what they herd. First the record of the original vowel as produced was played, and the observers were asked to record what they heard. It is needless to remark that out of the group of some hundred odd, practically no errors were made. Finally the artificial reproduction was made at the same end of the hook-up, placed in the other room where the source would not be visible to the observers. The *a* (ah) was generally recognized, but it was noted that almost any kind of horn could be substituted with much the same results. The *u* likewise gave fair results; but again it was observed that almost any long-narrow-necked bottle gave quite as good results. The *o* (oh) and some of the other back vowels came out fairly well where several were used so as to make them comparative; but where they were sprung the first thing, without any accompanying consonants, or any preceding vowels serving as comparative orientation, even they failed quite miserably; and this could not be said of the phonographic reproduction of the original. Distinction between front vowels *i* (ee) *ɪ* (it) ; *e* (bay) ɛ (eh) turned out the worst. And all were designated as clearly artificial.

The lower aperture corresponding to the glottis was then stopped, and the cavities stimulated as in a whisper, first through that end and then at the lips. The results were essentially the same as in the experiment indicated above, i.e. general failure. The pitch of the cavity (or cavities) of course appeared, just as do those of the mouth where either so actuated, or stimulated by percussion. And while in many cases the reproduction was quite as good as that of other artificial vowels which it has been the author's privilege

to hear, in no case, either where voiced or unvoiced, could one say that the reproduction was such that it actually gave the vowel originally produced. It has been the author's privilege to listen to most of the outstanding attempts thus far made to artificially reproduce vowels, including those of Helmholtz, Hermann, Koenig, Rousselot, Paget, Stewart, et al. Some, particularly Sir Richard Paget, have accomplished most interesting results. Paget knows the manipulation of his resonators and can handle them as no other who has made the attempt probably ever has been able to do. But he can do likewise with one cavity

FIG. 100-d. By inserting a vibrating reed in the hole above Sir Richard Paget makes this one crude cavity produce the most perfect imitation of human speech the author has heard from any vowel machine.

formed by his hands; and the author, as myriads of others have done, has heard him manipulate his fingers and cupped hands over a vibrating reed, in such a clever way as to make them say: "Laila I love you" and "Hello London are you there." And that includes quite as large a group of vowels as any of the others have used. So since his imitation is even better than their more complex ones, including the synthetic where the exact harmonics with their amplitudes as found present in the analyzed speech curve are reproduced, it

would seem to prove the theory that variation in one single crude resonator is all that is required for the creation of those quality differences which characterize the different vowels. Yet the author feels safe in saying that Paget would be the last one to make such an admission. Nor would he be the one to insist that any artificial vowels have thus far been reproduced by such resonators or systems, which a group of observers conducting an experiment like the one above outlined, could not distinguish from the human vowel if the latter were alternated with it.

To the author this seems to be the basic requirement in any such proof adduced to establish the authenticity of a vowel theory. And he agrees with D. C. Miller in his statement that:[1]

> "*The most convincing proof of a vowel theory would be a reproduction*" (not "of several vowels" as he says, but *of all vowels*) "*by compounding the partial* tones obtained in the analysis" of the recorded speech curve;

and that, a reproduction which would at least be accurate enough so that the average observer could not distinguish it from the original or phonographic recording of the same. Neither can he concede that it is justifiable to add a consonant to make the system say "mama, moo, maw, mat, meat," etc., or otherwise so conduct the experiment as to place the observer in a psychological attitude of mind or create a "set" for the vowel to be produced. And where this reproduction check is used, the final proof of any theory, will be manifest in our ability to recreate the fine distinctions in front vowel quality well enough so that a group of observers of this kind cannot differentiate them from the original — distinctions, for example, such as those manifest as between *i* (eat), and *ɪ* (it); or *e* (pate) and ɛ (pet). Those espousing theories often dis-

[1] MILLER, D. C. *Science of Musical Sounds* (1922) Macmillan 2nd. ed. p. 244.

metrically opposed, have succeeded in an artificial reproduction of the back vowels [from *a* (ah) to *u* (oo)] and some of the broader distinctions in the front vowels. And where theories are so opposite, both cannot be correct; hence the artificial reproduction must be considered to have been defective in some such way as not to add any conclusive proof. That defect, the author feels quite sure, lies in the fact that the experimenter has stopped short of carrying his experiment out to that ultimate goal.

So for this series of X-ray experiments, we would not be satisfied with anything less. And disappointing as it is we must admit, that the cavity tone theories, where limited to a consideration of the total volume of air and the cavity openings, functioning either as resonators or independent creators of the "vowel formant," all fail to receive confirmation.

The author only sees two ways out. **First,** the surfaces and shape of the cavity (i.e. area where the constriction takes place, whether against hard or soft surfaces), must be of greater importance than has heretofore been conceded. The author has developed a theory pertaining thereto, in his "Speech and Voice" (Macmillan). There appears to be no doubt but that soft un-tensed walls lower the pitch, and where radically constricted, dampen especially the high partials and thereby "mellow" or even "deaden" the tone before it escapes from the mouth. He extended an experiment of Miller's dealing with quality in organ pipes, and applied it to vowels. Miller's pipe was constructed of double walls so that the space between could be gradually filled with water. Says he:[1]

"While the space is filling, the tone quality changes conconspicuously thirty or forty times."

[1] MILLER, op. cit., p. 181.

And on the same page notes that merely by changing the tension in the walls of one of his zinc organ pipes, by grasping it firmly just above the mouth, he actually makes it squeal. And the author notes one of his own experiments with an organ pipe which is so pitched that it has an artificial quality most nearly approximating that of *a* (ah). By letting the end rest in the crotch between the thumb and forefinger and pinching in lightly as it sounds, it is made to speak *u* (oo) or *o* (oh) without altering the diameter of the mouth or lowering the pitch more than a fraction of a semi-tone. If such quality changes can be accomplished in "metallic" organ pipes merely by varying the tension of the walls, it stands to reason that the walls of the vocal cavities which are susceptible of such an infinite variety of tension and varying hardness or softness, could likewise alter quality.

Second, the author's laryngo-periskop makes it clear that the vocal cords themselves and the surfaces above them, take radically different positions in the production of the various vowels. So the original glottal tone may have present a varying composition of partials, thereby altering vowel quality ("mellowing" or making more "metallic") as those complex muscles vary their function. This apparatus makes it possible to examine that function, without pulling the tongue out with a cloth, depressing it, or otherwise impeding its movement by going in over the top thereof, as is required with broncoscopes or phonoscopes. The photographs taken by its help, show some of the variations in position taken by the surfaces which lie above the vocal cords. The manner in which the upper hump or forward *cushion of the epiglottis* creeps towards the *arytenoids* at the bottom (which is actually the back) would seem to the author to be of particular signific-

ance. For when such soft surfaces close over the vibrations of the vocal cords, the inevitable result would be one of damping. The high partials would be the first affected. And such a constriction would therefore inevitably result in a "mellowing" of the original glottal tone. It will be noted that the vocal cords are most exposed and free for *i* (ee), Fig. 41, and that they have been covered over, or that the cushion of the epiglottis has crept closest to the arytenoids, for *æ* (map) Fig. 37. Such a change is quite regularly observed. So we have noted here, another physiological factor which might be involved in creating vowel quality differences. Fig. 41 for *i* (ee) shows a vowel which might have the most "metallic" quality, and Fig. 38 ε (eh) one whose quality would be much "mellower" in consequence of the damping of glottal tone high partials by the closing over of interior laryngeal soft surfaces. And this function is one which could easily alternate with that of surfaces involved in the cavities above.

This conclusion leaves us with no necessity for comment on the cavity dimension computations which follow. They speak for themselves. The reader will note that they generally fail to completely confirm, the cavity tone and tongue arching theories now in vogue. And certainly it is true that they indicate the necessity for supplementing the total air volume-varied opening idea with some further explanation if we are to account for the vowel quality differences which were manifest in the original production.

The tables contain 1 cm. interval computations made from the X-ray photographs of various vowel tongue positions as taken by a large number of subjects. In general they are made to begin with the diameter of the laryngeal aperture, which falls as a rule at the

(.4)

cm. .5 .8 .5 .8 .7 (.4) .9 1.8

Diameters of cavity in median section 1.

at intervals of one centimeter

$3.^{1}$ $3.^{2}$ $2.^{9}$ $3.^{6}$ $3.^{3}$ $4.^{4}$ $3.^{3}$ 4. $(1.^{6})$

	Sq. cm.
Total area of median section	31.26
Area of neck alone..........	5.75
Area of back body..........	25.51

	Capacity of Cavity in Cu. cm.
Whole cavity...............	82.64
Front "Porch" or neck......	4.73
Back "belly" or body........	77.91

	cm.
Length of front neck........	8.5
Diam. of opening front lip...	.4
Velar......................	.4
Larynx.....................	1.6

Fig. 101. Vowel *y* (culte). French Subject 236. (with lip rounding)

upper tip of the Right Cornu. (See Frontispiece herein, for the location thereof in relation to the rest of the cavity.)

So far as has been within the author's power to forsee, every measurement is included which has been, or might be, thought to be of value in showing the resonating cavity (or in other words, the function of the air volume characteristic tone in its possible)

cm. $1.^{1}$ $(.^{4})$ $1.^{3}$ $1.^{4}$ $1.^{2}$ $(.^{6})$ $.^{8}$ $1.^{2}$

Diameters of cavity in median section at intervals of one centimeter

$3.^{4}$ $3.^{2}$ $3.^{2}$ $3.$ $3.^{4}$ $4.$ $3.$ $3.^{1}$ $(2.^{1})$

	Sq. cm.
Total area of median section	32.15
Area of neck alone..........	5.10
Area of back body..........	27.05

	Capacity of Cavity in Cu. cm.
Whole cavity...............	82.34
Front "Porch" or neck......	6.85
Back "belly" or body........	75.49

	cm.
Length of front neck........	7.5
Diam. of opening front lip...	.4
Velar.....................	.6
Larynx....................	2.1

Fig. 102. *y* (culte) French (St. Cloud-Paris). Subject 236. (without lip rounding)

influence on vowel quality. It would be a waste of time for the author to compute the tones which those cavities would show, according to the various theories heretofore applied. For in all probability, each scientist will proceed to interpret the results in a different manner, in order to make the facts fit his theory, if that be possible.

It might be well to give at least one of the characteristic mathematical formulae which have been used to

cm. 2.2 (1.1) 1.5 3.0 2.2 2.3 1.9 1.7 (1.4) 1.5

Diameters of cavity in median section 1.6 3.0 2.4 2.2 2.5 2.7 2.0 (.7)

at intervals of one centimeter

	Sq. cm.
Total area of median section	32.40
Area of neck alone...........	14.65
Area of back body..........	17.75

	Capacity of Cavity in Cu. cm.
Whole cavity...............	64.14
Front "Porch" or neck......	28.37
Back "belly" or body........	35.77

	cm.
Length of front neck........	9.
Diam. of opening front lip...	1.1
Velar.......................	1.4
Larynx.....................	.7

Fig. 103. ϕ (jeudi) French Subject 236.
(with lip rounding)

account for vowel quality. The reader who desires may make application thereof to each table. This will be found in Lord Rayleigh's *Theory of Sound,* vol. II, p. 173, as it pertains to bottles with long necks, established experimentally by Sondhauss; and in *Speech Sounds: their nature and causation,* appearing in Phonetische Studien (the earlier title of Neuere Sprachen) III (1890) p. 275, 278, IV (1890) p. 39, V (1891) p. 125, as applied by Lloyd (R. J.) to air

cm. (.4) 2.2 1.8 1.5 (1.0) 1.2 1.4 2.4

Diameters of cavity in median section at intervals of one centimeter

2.3
3.4
2.6
2.3
1.9
1.7
2.1
2.8
(1.1)

	Sq. cm.
Total area of median section	26.29
Area of neck alone..........	7.28
Area of back body..........	19.01

	Capacity of Cavity in Cu. cm.
Whole cavity...............	54.56
Front "Porch" or neck......	16.20
Back "belly" or body........	38.36

	cm.
Length of front neck........	8.
Diam. of opening front lip...	.4
Velar......................	1.
Larynx.....................	1.1

Fig. 104. Vowel ϕ (jeudi). Subject 236. French. (no lip rounding)

volume or resonating vowel cavity influence in creating vowel quality.

Where

V = Speed of sound (which at the average temperature of air in the speech cavity — say 35° Centigrade would be, 341,375 mm. per second).

L = Length of the bottle neck, or front mouth cavity in millimeters.

A = The cross section area of the neck in square millimeters, (which in the case of our tables would be

(.4)

cm. .5 1.3 2.9 4.7 3.1 1.8 1.1 (.4) .6 .8

Diameters of cavity in median section

at intervals of one centimeter

.8 1.5 2.3 3.1 3.1 3.1 3.4 (1.4)

	Sq. cm.
Total area of median section	29.27
Area of neck alone..........	13.27
Area of back body..........	16.

	Capacity of Cavity in Cu. cm.
Whole cavity...............	65.44
Front "Porch" or neck......	37.35
Back "belly" or body........	38.09

	cm.
Length of front neck........	10.5
Diam. of opening front lip...	.4
Velar....................	.4
Larynx....................	1.4

Fig. 105. Vowel *u* (Rouge). Subject 236. French.

taken as the square of the average diameter of the narrow tube; but since the formula calls for the square root of the area, the average diameter itself would give us the figure which we could use without the necessity for extracting the square root).

S = The volume, or the air capacity of the cavity as a whole, figured in cubic millimeters.

The formulae read:

$$(1) \qquad n = \frac{V}{2\ L}$$

$$(2) \qquad N = 46{,}705\ \frac{\sqrt{A}}{\sqrt{L}\quad \sqrt{S}}$$

The final result will show in double vibrations per second: a high pitch for the narrow neck ($= n$) and a low pitch for the whole cavity ($=$ N). Lloyd himself, would have ascribed the vowel quality to the *radical ratio* (R) or relation between the two. So $R = \frac{n}{N}$

We might take the figures which he gives for *u* (oo) to serve us as an example:

V, or Speed of sound as given above, 341,375 mm. per second.
A, or Cross section area of the tube = 93 mm.²
L, or Length of the narrow neck or tube = 50.6 mm.
S, or Capacity of the bottle as a whole=185,326 mm.²

Applying the formulae we get:

$$n = \frac{341{,}375}{2 \times 50.6} = 3{,}373 \text{ or between } \mathbf{g}_4 \text{ and } \mathbf{a}_4$$

$$N = 46{,}705 \times \frac{\sqrt{93}}{\sqrt{50.6} \times \sqrt{185{,}326}} = 147 \text{ or } \mathbf{d}$$

$R = \frac{n}{N}$ and since A $\times$ L or the cross section square area times the length of the tube, is nothing more than the total capacity of that neck which we can let $= s$ we have

$$R = 3.6546\ \frac{\sqrt{S}}{\sqrt{s}} \text{ or } R = 3.6546\ \frac{\sqrt{4705.8}}{\sqrt{185{,}326}}$$

which radical ratio would according to Lloyd be responsible for the quality of the vowel. Even a cursory examination of our X-ray experiments as analyzed in these tables shows they fail to sustain such theories as all-sufficient explanations of vowel quality.

cm. $1.^{8}$ $(1.^{5})$ $1.^{6}$ $3.$ $3.^{6}$ $3.$ $2.^{6}$ $1.^{8}$ $1.^{9}$ $(1.^{9})$

Diameters of cavity in median section at intervals of one centimeter

$1.^{3}$ $1.^{4}$ $1.^{6}$ $(1.^{2})$ $1.^{4}$ $2.^{3}$ $(1.^{4})$

	Sq. cm.
Total area of median section	29.90
Area of neck alone..........	20.47
Area of back body..........	9.43

	Capacity of Cavity in Cu. cm.
Whole cavity...............	64.27
Front "Porch" or neck......	52.58
Back "belly" or body........	11.69

	cm.
Length of front neck........	9.5
Diam. of opening front lip...	1.5
Velar.....................	1.9
Epiglottis.................	1.2
Larynx....................	1.4

Fig. 106. Vowel ə (me). Subject 236.

cm. .8 (.9) 1.0 2.2 3.6 2.5 2.8 2. 1.3 1.1 .9 .4 (.8)

Diameters of cavity in median section at intervals of one centimeter

.1 .7 .9 1.4 1.7 1.9 2.6 3.1 (1.2)

	Sq. cm.
Total area of median section	28.46
Area of neck alone..........	17.94
Area of back body..........	10.52

	Capacity of Cavity in Cu. cm.
Whole cavity...............	50.97
Front "Porch" or neck......	30.48
Back "belly" or body........	20.49

	cm.
Length of front neck........	10.5
Diam. of opening front lip...	.6
Velar.....................	.3
Larynx...................	1.2

Fig. 107. Vowel *o* (Rose). French Subject 236.

cm. $2.^2$ $(1.^7)$ $1.^9$ $3.^1$ $5.^1$ $5.^8$ $3.^5$ $3.$ $2.$ $1.^7$ $1.^1$ $.^9$

Diameters of cavity in median section at intervals of one centimeter

$.^5$ $(.^3)$ $.^4$ $.^8$ $1.^0$ $1.^2$ $1.^7$ $2.^7$ $(1.^2)$

	Sq. cm.
Total area of median section	36.33
Area of neck alone..........	29.96
Area of back body..........	6.37

	Capacity of Cavity in Cu. cm.
Whole cavity...............	93.52
Front "Porch" or neck......	83.61
Back "belly" or body........	9.89

	cm.
Length of front neck........	10.5
Diam. of opening front lip...	1.7
Velar......................	.3
Larynx.....................	1.2

Fig. 108. Vowel ɔ (Robe). French Subject 236.

cm. $1.^{9}$ $(1.^{7})$ $2.$ $3.^{7}$ $4.^{1}$ $3.^{6}$ $3.$ $2.^{1}$ $1.^{3}$ $1.^{2}$ $1.^{1}$ $(.^{9})$

Diameters of cavity in median section at intervals of one centimeter

$1.^{2}$
$.^{9}$
$(.^{6})$
$.^{8}$
$1.^{5}$
$2.^{9}$
$(1.^{3})$
$1.^{6}$

	Sq. cm.
Total area of median section	31.09
Area of neck alone..........	23.54
Area of back body..........	7.55

	Capacity of Cavity in Cu. cm.
Whole cavity...............	67.40
Front "Porch" or neck......	54.49
Back "belly" or body........	12.91

	cm.
Length of front neck........	10.
Diam. of opening front lip...	1.7
Velar.....................	.6
Epiglottis..................	.6
Larynx....................	1.3

Fig. 109. Vowel *a* (âme). Subject 236.

cm. $1.^{6}$ $(1.^{3})$ $2.^{1}$ $3.^{4}$ $3.$ $3.^{6}$ $3.^{6}$ $3.$ $2.^{6}$ $1.^{9}$ $2.$ $(1.^{9})$

Diameters of cavity in median section at intervals of one centimeter

$2.^{2}$ $1.^{5}$ $1.^{6}$ $(1.^{1})$ $1.^{3}$ $1.^{5}$ $2.^{2}$ $(1.^{3})$

	Sq. cm.
Total area of median section	31.32
Area of neck alone..........	21.73
Area of back body..........	9.59

	Capacity of Cavity in Cu. cm.
Whole cavity...............	67.43
Front "Porch" or neck......	52.96
Back "belly" or body........	14.47

	cm.
Length of front neck........	9.
Diam. of opening front lip...	1.3
Velar.....................	1.9
Epiglottis.................	1.1
Larynx....................	1.3

Fig. 110. Vowel Æ (femme). French Subject 236.

cm. $1.^{9}$ $(1.^{1})$ $1.^{9}$ $.^{9}$ $.^{9}$ $.^{8}$ $(.^{8})$

Diameters of cavity in median section at intervals of one centimeter

$1.^{4}$ $3.$ $3.^{2}$ $3.^{4}$ $3.^{7}$ $4.$ $4.$ $3.^{2}$ $(1.^{7})$

	Sq. cm.
Total area of median section	30.51
Area of neck alone..........	6.46
Area of back body..........	24.05

	Capacity of Cavity in Cu. cm.
Whole cavity...............	77.25
Front "porch" or neck......	7.67
Back "belly" or body........	69.58

	cm.
Length of front neck........	7.5
Diam. of opening front lip...	1.1
Velar.....................	.3
Larynx...................	1.7

Fig. 111. Vowel *i* (si). French Subject 236.

cm. $2.$ $(1.^{2})$ $2.$ $3.^{5}$ $1.^{4}$ $1.^{2}$ $.^{7}$ $.^{6}$ $(.^{5})$ $1.^{0}$

Diameters of cavity in median section at intervals of one centimeter

$1.^{6}$ $2.^{5}$ $2.^{6}$ $2.^{9}$ $3.^{3}$ $3.^{7}$ $2.^{7}$ $3.^{2}$ $(1.^{4})$

	Sq. cm.
Total area of median section	30.42
Area of neck alone..........	8.97
Area of back body..........	21.45

	Capacity of Cavity in Cu. cm.
Whole cavity................	71.76
Front "Porch" or neck......	51.76
Back "belly" or body........	20.

	cm.
Length of front neck........	7.5
Diam. of opening front lip...	1.2
Velar.....................	.5
Larynx....................	1.4

Fig. 112. Vowel *i* (lire). French Subject 236.

cm. 1.9 (1.2) 2.6 1.5 1.2 .9 .8 .8 (.7)

Diameters of cavity in median section at intervals of one centimeter

1.7 2.1 2.8 3.1 3.4 3.7 2.5 2.8 2.4 (1.9)

	Sq. cm.
Total area of median section	31.46
Area of neck alone..........	8.51
Area of back body..........	22.95

	Capacity of Cavity in Cu. cm.
Whole cavity...............	67.41
Front "Porch" or neck......	12.66
Back "belly" or body........	54.75

	cm.
Length of front neck........	7.5
Diam. of opening front lip...	1.2
Velar.....................	.7
Larynx....................	1.9

Fig. 113. Vowel *e* (blé). French Subject 236.

cm. (1.9) 1.9 3. 2.1 2.3 2. 1.7 2. 2.3 (1.7)

Diameters of cavity in median section at intervals of one centimeter

2.7 2.9 2.9 2.2 2. 2.2 1.2 (1.1) 1.5

	Sq. cm.
Total area of median section	35.79
Area of neck alone..........	17.85
Area of back body..........	27.94

	Capacity of Cavity in Cu. cm.
Whole cavity...............	62.64
Front "Porch" or neck......	30.19
Back "belly" or body........	32.45

	cm.
Length of front neck........	8.
Diam. of opening front lip...	1.9
Velar.....................	1.7
Larynx....................	1.1

Fig. 114. Vowel ɛ (bête). French Subject 236.

cm. 2.5 (1.2) 2.6 2.2 1.6 .7 (.5)

Diameters of cavity in median section

at intervals of one centimeter

.7 4.2 3.7 3.4 3.4 3.2 2.9 (1.8) 2.0 2.6 (1.5) 1.9

	Sq. cm.
Total area of median section	25.16
Area of neck alone..........	7.91
Area of back body..........	33.07

	Capacity of Cavity in Cu. cm.
Whole cavity...............	85.60
Front "Porch" or neck......	16.61
Back "belly" or body........	68.99

	cm.
Length of front neck........	6.
Diam. of opening front lip...	1.2
Velar......................	.5
Epiglottis.................	1.8
Larynx....................	1.5

Fig. 153. Vowel *i* (si). Italian Subject 347.

cm. $2.^{1}$ $(1.^{7})$ $2.^{2}$ $2.$ $1.$ $(.^{4})$ $1.^{0}$

Diameters of cavity in median section $3.^{6}$ $3.^{7}$ $3.^{5}$ $3.^{2}$ $3.$ $2.^{9}$ $(1.^{7})$ $2.^{1}$ $(1.^{3})$ $1.^{8}$ $2.^{5}$

at intervals of one centimeter

	Sq. cm.
Total area of median section	33.83
Area of neck alone..........	7.38
Area of back body..........	26.45

	Capacity of Cavity in Cu. cm.
Whole cavity..............	77.81
Front "Porch" or neck......	12.10
Back "belly" or body........	65.71

	cm.
Length of front neck........	6.5
Diam. of opening front lip...	1.
Velar......................	.4
Epiglottis..................	1.7
Larynx....................	1.3

Fig. 154. Vowel *e* (se). Italian Subject 347.

cm. 1.8 (1.4) 2.4 1.4 1.9 1.7 1.3 (1.3) 2.

Diameters of cavity in median section at intervals of one centimeter

.6 3.4 3.4 3. 2.4 (.9) 2. 1.5 2.2 1.4 (1.4)

	Sq. cm.
Total area of median section	26.25
Area of neck alone..........	10.62
Area of back body..........	15.63

	Capacity of Cavity in Cu. cm.
Whole cavity..............	59.63
Front "Porch" or neck......	19.36
Back "belly" or body........	40.27

	cm.
Length of front neck........	8.
Diam. of opening front lip...	1.4
Velar.....................	1.3
Epiglottis.................	.9
Larynx....................	1.4

Fig. 155. Vowel *a* (la). Italian Subject 347.

cm. $(1.^{2})$ $1.^{7}$ $2.^{1}$ $3.$ $3.^{3}$ $2.^{7}$ $2.^{3}$ $2.^{2}$ $(1.^{5})$

Diameters of cavity in median section at intervals of one centimeter

$2.^{3}$ $1.^{8}$ $1.^{8}$ $.^{8}$ $(.^{7})$ $.^{9}$ $1.^{3}$ $2.^{2}$ $(1.^{2})$ $2.$

	Sq. cm.
Total area of median section	29.03
Area of neck alone..........	18.71
Area of back body..........	10.32

	Capacity of Cavity in Cu. cm.
Whole cavity...............	57.73
Front "Porch" or neck......	40.81
Back "belly" or body........	16.92

	cm.
Length of front neck........	8.5
Diam. of opening front lip...	1.2
Velar.....................	1.5
Epiglottis..................	.7
Larynx....................	1.2

Fig. 156. Vowel *o* (no). Italian Subject 347.

cm. .9 (.7) 1.2 1.6 1.7 2.1 1.8 1.5 .9 .7 (.3) .5

Diameters of cavity in median section at intervals of one centimeter

1.2 .9 .7 .9 (1.6) 1.8 2.5 (1.3) 1.5

	Sq. cm.
Total area of median section	19.65
Area of neck alone..........	9.48
Area of back body..........	10.17

	Capacity of Cavity in Cu. cm.
Whole cavity...............	30.04
Front "Porch" or neck......	14.99
Back "belly" or body........	15.05

	cm.
Length of front neck........	9.5
Diam. of opening front lip...	.7
Velar.....................	.3
Epiglottis.................	1.6
Larynx...................	1.3

Fig. 157. Vowel *u* (dun). Italian Subject 347.

(.5)

cm. 1.6 .8 1.1 1.2 .8 .8 (.8) 1.3

Diameters of cavity in median section at intervals of one centimeter

2.4
3.4
3.
2.9
2.6
2.7
1.8
1.9
2.3
(1.2)

	Sq. cm.
Total area of median section	29.33
Area of neck alone..........	6.22
Area of back body..........	23.11

	Capacity of Cavity in Cu. cm.
Whole cavity...............	48.19
Front "Porch" or neck......	5.40
Back "belly" or body........	42.79

	cm.
Length of front neck........	8.
Diam. of opening front lip...	.5
Velar......................	.8
Larynx.....................	1.2

Fig. 158. Vowel *i* (mí). Spanish Subject 358.

cm. ($1.^{4}$) $1.^{9}$ $1.^{9}$ $1.^{8}$ $.^{9}$ ($.^{9}$)

Diameters of cavity in median section at intervals of one centimeter

$3.^{0}$ $3.^{0}$ $3.^{6}$ $2.^{8}$ $2.^{1}$ $1.^{9}$ $1.^{5}$ $1.^{7}$ $2.^{5}$ ($.^{9}$)

	Sq. cm.
Total area of median section	29.35
Area of neck alone..........	6.93
Area of back body..........	22.42

	Capacity of Cavity in Cu. cm.
Whole cavity...............	56.67
Front "Porch" or neck......	11.02
Back "belly" or body........	45.65

	cm.
Length of front neck........	6.5
Diam. of opening front lip...	1.4
Velar.....................	.9
Larynx....................	.9

Fig. 159. Vowel *e* (me). Spanish Subject 358.

cm. 2.9 (1.5) 2.1 2.6 2.6 2.8 2.6 (2.6)

Diameters of cavity in median section

at intervals of one centimeter

.7
2.6
3.8
2.3
1.4
1.1
.8
(.4)
.7
.8
2.
(1.0)
1.4

	Sq. cm.
Total area of median section	31.73
Area of neck alone..........	13.66
Area of back body..........	18.07

	Capacity of Cavity in Cu. cm.
Whole cavity...............	65.20
Front "Porch" or neck......	37.38
Back "belly" or body........	27.82

	cm.
Length of front neck........	7.
Diam. of opening front lip...	1.5
Velar.....................	2.6
Epiglottis..................	.4
Larynx....................	1.4

Fig. 160. Vowel *a* (la). Spanish Subject 358.

cm. 2.4 1.0 (.8) 1.2 1.6 2.4 3.2 3.2 2.8 2.6 1.9 1.3 (1.)

Diameters of cavity in median section at intervals of one centimeter

.8 .2 .4 1.4 1.1 .9 1.0 (.9) 1.5 2.5 (1.6)

	Sq. cm.
Total area of median section	32.37
Area of neck alone..........	21.41
Area of back body..........	10.96

	Capacity of Cavity in Cu. cm.
Whole cavity...............	59.37
Front "Porch" or neck......	45.03
Back "belly" or body........	14.34

	cm.
Length of front neck........	10.
Diam. of opening front lip...	.8
Velar.....................	1.0
Epiglottis..................	.9
Larynx....................	1.6

Fig. 161. Vowel *o* (no). Spanish Subject 358.

cm. 1.4 (.3) .8 1.0 1.7 2.1 2. 1.6 1.0 .4 (.2) .7

Diameters of cavity in median section at intervals of one centimeter

.4
1.1
1.1
1.2
1.6
2.
2.1
2.4
3.3
(1.5)

	Sq. cm.
Total area of median section	26.54
Area of neck alone..........	10.93
Area of back body..........	15.61

	Capacity of Cavity in Cu. cm.
Whole cavity...............	42.70
Front "Porch" or neck......	15.66
Back "belly" or body........	27.04

	cm.
Length of front neck........	10.5
Diam. of opening front lip...	.3
Velar......................	.2
Larynx....................	1.5

Fig. 162. Vowel *u* (su). Spanish Subject 358.

cm. $1.^{2}$ $(.^{4})$ $1.^{1}$ $1.^{3}$ $.^{8}$ $(.^{6})$ $.^{7}$

Diameters of cavity in median section

at intervals of one centimeter

$2.^{5}$
$2.^{8}$
$2.^{7}$
$2.^{6}$
$2.^{0}$
$1.^{9}$
$2.^{4}$
$(1.^{7})$

	Sq. cm.
Total area of median section	21.04
Area of neck alone..........	4.61
Area of back body..........	16.43

	Capacity of Cavity in Cu. cm.
Whole cavity...............	37.28
Front "Porch" or neck......	4.56
Back "belly" or body........	32.72

	cm.
Length of front neck........	6.
Diam. of opening front lip...	.4
Velar.....................	.6
Larynx...................	1.7

Fig. 163. Vowel *i* (peep). Subject 291.

cm. $.^{8}$ $(.^{4})$ $1.^{3}$ $1.^{9}$ $2.^{1}$ $1.^{9}$ $(1.^{8})$ $2.^{1}$

Diameters of cavity in median section 2. $3.^{1}$ $2.^{8}$ $2.^{4}$ $1.^{5}$ 1. $1.^{4}$ $(1.^{1})$

at intervals of one centimeter

	Sq. cm.
Total area of median section	23.11
Area of neck alone..........	10.17
Area of back body..........	12.94

	Capacity of Cavity in Cu. cm.
Whole cavity...............	42.31
Front "Porch" or neck......	16.92
Back "belly" or body........	25.39

	cm.
Length of front neck........	6.5
Diam. of opening front lip...	.4
Velar......................	1.8
Larynx.....................	1.1

Fig. 164. Vowel *ɪ* (pip). Subject 291.

cm. $(1.^{2})$ $1.^{7}$ $2.^{5}$ $2.^{1}$ $1.^{3}$ $1.^{1}$ $(1.^{1})$

Diameters of cavity in median section

at intervals of one centimeter

$3.^{4}$
$2.^{9}$
$2.^{6}$
$2.^{5}$
$2.^{3}$
$1.^{6}$
$(1.^{1})$

	Sq. cm.
Total area of median section	22.49
Area of neck alone..........	8.20
Area of back body..........	14.29

	Capacity of Cavity in Cu. cm.
Whole cavity...............	45.87
Front "Porch" or neck......	13.83
Back "belly" or body........	32.04

	cm.
Length of front neck........	6.
Diam. of opening front lip...	1.2
Velar.....................	1.1
Larynx....................	1.1

Fig. 165. Vowel *e* (fame). Mid-East U. S. Lady. Subject 291.

cm. (.9) 1.5 2.1 2.4 2.2 2.1 (2.)

Diameters of cavity in median section at intervals of one centimeter

3.1 2.1 1.5 .8 1.3 1.1 (.4) .9

	Sq. cm.
Total area of median section	24.75
Area of neck alone..........	10.89
Area of back body..........	13.86

	Capacity of Cavity in Cu. cm.
Whole cavity...............	36.26
Front "Porch" or neck......	20.11
Back "belly" or body........	16.15

	cm.
Length of front neck........	6.
Diam. of opening front lip...	.9
Velar.....................	2.0
Larynx....................	.4

Fig. 166. Vowel ɛ (pep). Mid-East U. S. Lady. Subject 291.

cm. 2.5 (1.4) 2.2 3. 3.3 2.7 2.2 2.1 (1.8)

Diameters of cavity in median section at intervals of one centimeter

2.2 3.1 2.5 1.5 .6 .8 (.3) .9

	Sq. cm.
Total area of median section	26.76
Area of neck alone..........	15.06
Area of back body..........	11.70
	Capacity of Cavity in Cu. cm.
Whole cavity...............	59.26
Front "Porch" or neck......	37.26
Back "belly" or body........	22.
	cm.
Length of front neck........	6.
Diam. of opening front lip...	1.4
Velar	1.8
Larynx....................	.3

Fig. 167. Vowel æ (pap). Subject 291.

cm. $(.^{9})$ $1.^{7}$ $3.$ $3.^{6}$ $3.^{4}$ $2.^{7}$ $1.^{9}$ $2.^{1}$ $(1.^{6})$

Diameters of cavity in median section

at intervals of one centimeter

$1.^{3}$
$1.^{1}$
$.^{7}$
$(.^{2})$
$.^{3}$
$1.^{0}$
$(.^{4})$
$1.^{0}$

	Sq. cm.
Total area of median section	23.56
Area of neck alone..........	18.90
Area of back body..........	4.66

	Capacity of Cavity in Cu. cm.
Whole cavity...............	46.46
Front "Porch" or neck......	43.16
Back "belly" or body........	3.30

	cm.
Length of front neck........	8.
Diam. of opening front lip...	.9
Velar......................	1.6
Epiglottis..................	.2
Larynx.....................	.4

Fig. 168. Vowel *a* (balm). Mid-East U. S. Lady. Subject 291.

cm. 2.2 (1.2) 2.0 3.6 3.7 4.1 3.4 2.3 1.4 .8 (.4) .9 .4 .3 (.2) .7 (.2)

Diameters of cavity in median section at intervals of one centimeter

	Sq. cm.
Total area of median section	23.69
Area of neck alone..........	20.91
Area of back body..........	2.78

	Capacity of Cavity in Cu. cm.
Whole cavity...............	46.91
Front "Porch" or neck......	42.56
Back "belly" or body........	4.35

	cm.
Length of front neck........	8.5
Diam. of opening front lip...	1.2
Velar......................	.4
Epiglottis..................	.2
Larynx.....................	.2

Fig. 169. Vowel ɔ (paw). Subject 291. Lady.

cm. $1.^{4}$ $(.^{9})$ $2.^{0}$ $3.^{0}$ $3.^{5}$ $3.^{3}$ $2.^{7}$ $2.^{3}$ $1.^{8}$ $(1.^{6})$

Diameters of cavity in median section at intervals of one centimeter

1. $1.^{3}$ $.^{7}$ $.^{6}$ $(.^{3})$ $.^{5}$ $(.^{3})$

	Sq. cm.
Total area of median section	24.51
Area of neck alone..........	20.59
Area of back body..........	3.92

	Capacity of Cavity in Cu. cm.
Whole cavity...............	48.00
Front "Porch" or neck......	44.28
Back "belly" or body........	3.72

	cm.
Length of front neck........	8.5
Diam. of opening front lip...	.9
Velar....................	1.6
Epiglottis.................	.3
Larynx...................	.3

Fig. 170. Vowel ə (the). Subject 291.

cm. $1.^{0}$ $(.^{5})$ $1.^{8}$ $2.^{8}$ $3.^{2}$ $2.^{9}$ $2.^{1}$ $1.^{4}$ $1.^{3}$ $(1.^{2})$ $1.^{3}$ $.^{6}$ $1.^{1}$ $.^{6}$ $.^{9}$ $(.^{4})$ $.^{6}$ $.^{9}$ $(.^{4})$

Diameters of cavity in median section at intervals of one centimeter

	Sq. cm.
Total area of median section	21.83
Area of neck alone..........	18.16
Area of back body..........	3.67

	Capacity of Cavity in Cu. cm.
Whole cavity...............	34.79
Front "Porch" or neck......	31.72
Back "belly" or body........	3.07

	cm.
Length of front neck........	9.
Diam. of opening front lip...	.5
Velar.....................	1.2
Epiglottis.................	.4
Larynx....................	.4

Fig. 171. Vowel *U* (foot). Subject 291.

cm. 1.5 1.0 (.5) 2.5 3.4 3.6 2.6 1.5 1.0 1.0 (.6)

Diameters of cavity in median section 1.2

at intervals of one centimeter

.7
.6
1.0 (.7)
.8
1.6 (.7)
1.3

	Sq. cm.
Total area of median section	24.08
Area of neck alone..........	17.29
Area of back body..........	6.79

	Capacity of Cavity in Cu. cm.
Whole cavity...............	41.84
Front "Porch" or neck......	35.44
Back "belly" or body........	6.40

	cm.
Length of front neck........	9.
Diam. of opening front lip...	.5
Velar......................	.6
Epiglottis..................	.7
Larynx.....................	.7

Fig. 172. Vowel *o* (oh). Subject 291.

(.3) (.2)

cm. .4 .7 1.0 2.3 2.3 1.7 1.0 .4 .3 .4

Diameters of cavity in median section at intervals of one centimeter

1.1
1.3
1.6
1.5
1.6
2.1
(1.8)

	Sq. cm.
Total area of median section	18.66
Area of neck alone..........	10.31
Area of back body..........	8.35

	Capacity of Cavity in Cu. cm.
Whole cavity...............	24.86
Front "Porch" or neck......	13.38
Back "belly" or body........	11.48

	cm.
Length of front neck........	10.
Diam. of opening front lip...	.3
Velar.....................	.2
Larynx....................	1.8

Fig. 173. Vowel *u* (moo). Subject 291.

cm. (.3) .7 1.3 1.2 .4 (.5)

Diameters of cavity in median section at intervals of one centimeter

3.1
2.7
2.6
2.6
2.8
3.
2.5
(2.4)

	Sq. cm.
Total area of median section	26.55
Area of neck alone..........	4.95
Area of back body..........	21.60

	Capacity of Cavity in Cu. cm.
Whole cavity...............	49.60
Front "Porch" or neck......	3.16
Back "belly" or body........	46.44

	cm.
Length of front neck........	6.
Diam. of opening front lip...	.3
Velar.....................	.5
Larynx....................	2.4

Fig. 174. Vowel *i* (peep). Rocky Mt. U. S. child. Subject 202.

cm. (2.8) 2.4 2.2 2.0 1.8 (1.8)

Diameters of cavity in median section at intervals of one centimeter

3.1
3.7
3.1
2.6
2.0
1.8
1.5
2.0
(1.8)

	Sq. cm.
Total area of median section	25.60
Area of neck alone..........	7.35
Area of back body..........	18.25

	Capacity of Cavity in Cu. cm.
Whole cavity...............	56.01
Front "Porch" or neck......	14.09
Back "belly" or body........	41.92

	cm.
Length of front neck........	5.
Diam. of opening front lip...	2.3
Velar.....................	1.3
Larynx....................	1.3

Fig. 175. Vowel *ɪ* (pip.) Rocky Mt. U. S. child. Subject 202.

cm. (1.5) 1.7 1.3 1.4 .8 (.4) .7 1.8

Diameters of cavity in median section at intervals of one centimeter

1.8 1.8 1.5 1.4 1.5 2.5 (2.1)

	Sq. cm.
Total area of median section	19.03
Area of neck alone..........	5.87
Area of back body..........	13.16

	Capacity of Cavity in Cu. cm.
Whole cavity...............	30.09
Front "Porch" or neck......	8.68
Back "belly" or body........	21.41

	cm.
Length of front neck........	8.
Diam. of opening front lip...	1.5
Velar.....................	.4
Larynx....................	2.1

Fig. 176. Vowel *e* (pape). Subject 202. Rcky. Mt. U. S. child.

cm. $(1.^{0})$ $1.^{6}$ $1.^{5}$ $1.^{3}$ $1.$ $(0.^{7})$ $1.$ $2.^{2}$ $1.^{8}$ $2.^{5}$ $2.$ $2.$ $1.^{6}$ $2.^{8}$ $3.^{6}$ $(1.^{6})$

Diameters of cavity in median section at intervals of one centimeter

	Sq. cm.
Total area of median section	24.49
Area of neck alone..........	6.19
Area of back body..........	18.30

	Capacity of Cavity in Cu. cm.
Whole cavity...............	50.56
Front "Porch" or neck......	7.06
Back "belly" or body........	43.50

	cm.
Length of front neck........	7.
Diam. of opening front lip...	1.
Velar......................	.7
Larynx.....................	1.6

Fig. 177. Vowel ɛ (pep). Subject 202. Rocky Mt. U. S. Girl.

cm. 1.6 (.5) 1.0 1.0 1.6 1.1 .9 (.8) .9 1.2

Diameters of cavity in median section at intervals of one centimeter

1.4 2.5 2.1 1.7 .9 (1.1)

	Sq. cm.
Total area of median section	13.15
Area of neck alone..........	6.60
Area of back body..........	6.55

	Capacity of Cavity in Cu. cm.
Whole cavity...............	22.37
Front "Porch" or neck......	8.94
Back "belly" or body........	13.43

	cm.
Length of front neck........	9.
Diam. of opening front lip...	.5
Velar.....................	.6
Larynx..................	1.1

Fig. 178. Vowel *e* (pape). Subject 202.

cm. $(1.^{1})$ $1.^{1}$ $1.^{8}$ $1.^{9}$ $1.^{2}$ $(.^{8})$ $1.^{2}$

Diameters of cavity in median section

	Sq. cm.
Total area of median section	16.21
Area of neck alone..........	6.94
Area of back body..........	9.27

	Capacity of Cavity in Cu. cm.
Whole cavity...............	32.44
Front "Porch" or neck......	10.03
Back "belly" or body........	22.41

	cm.
Length of front neck........	7.
Diam. of opening front lip...	1.1
Velar......................	.8
Larynx....................	1.3

at intervals of one centimeter

$2.^{5}$ $3.^{4}$ $2.^{5}$ $1.^{4}$ $.^{6}$ $.^{7}$ $(1.^{3})$

Fig. 179. Vowel æ (pap). Subject 202.

cm. (2.0) 2.6 3.3 3.7 3.5 3. 2.3 2.1 1.7 (.9) .5 1. .5 (.5) .5 (.5)

Diameters of cavity in median section at intervals of one centimeter

	Sq. cm.
Total area of median section	25.31
Area of neck alone..........	22.19
Area of back body..........	3.12

	Capacity of Cavity in Cu. cm.
Whole cavity...............	52.87
Front "Porch" or neck......	51.08
Back "belly" or body........	1.79

	cm.
Length of front neck........	9.5
Diam. of front opening lip...	2.
Velar.....................	.9
Epiglottis..................	.5
Larynx....................	.5

Fig. 180. Vowel *a* (balm). Subject 202.

cm. $(1.^{2})$ $2.^{3}$ $1.^{7}$ $2.^{5}$ $1.^{8}$ $1.$ $(1.)$ $1.^{3}$ $2.^{0}$ $1.^{5}$ $.^{9}$ $.^{4}$ $(.^{3})$ $(.^{3})$

Diameters of cavity in median section at intervals of one centimeter

	Sq. cm.
Total area of median section	10.69
Area of neck alone..........	8.97
Area of back body..........	1.72

	Capacity of Cavity in Cu. cm.
Whole cavity...............	21.27
Front "Porch" or neck......	20.27
Back "belly" or body........	1.

	cm.
Length of front neck........	9.5
Diam. of opening front lip...	1.2
Velar.....................	1.
Epiglottis..................	.3
Larynx....................	.3

Fig. 181. Vowel *a* (balm). Subject 202.

cm. 2.3 (1.3) 2. 2.9 3.1 3.2 2.4 2 2 2 (1.7) 1.9 .8 .2 .8 1.0 1.0 .4 .4 (.2) .4 (.2)

Diameters of cavity in median section at intervals of one centimeter

	Sq. cm.
Total area of median section	25.16
Area of neck alone..........	21.11
Area of back body..........	4.05

	Capacity of Cavity in Cu. cm.
Whole cavity...............	49.22
Front "Porch" or neck......	46.22
Back "belly" or body........	3.

	cm.
Length of front neck........	9.5
Diam. of opening front lip...	1.3
Velar....................	1.7
Epiglottis.................	.2
Larynx....................	.2

Fig. 182. Vowel ɔ (paw). Subject 202.

cm. (.9) 1.1 2.1 2.3 2.8 2.4 1.8 1.6 1.6 (.7) 1.4

.5 .6 1.7 1.4 .6 (.4) .5 1.3 (.4)

Diameters of cavity in median section at intervals of one centimeter

	Sq. cm.
Total area of median section	20.26
Area of neck alone..........	16.42
Area of back body..........	3.84

	Capacity of Cavity in Cu. cm.
Whole cavity...............	35.36
Front "Porch" or neck......	27.32
Back "belly" or body........	8.04

	cm.
Length of front neck........	9.5
Diam. of opening front lip...	.9
Velar......................	.7
Epiglottis.................	.4
Larynx....................	.4

Fig. 183. Vowel ɔ (paw). Subject 202.

Diameters of cavity in median section at intervals of one centimeter

cm. 1.4 (.7) 2.1 2.4 2.7 2.3 (1.5) 2. 2. .4 .4 1.4 1.2 .6 (.3) .8 (.8)

	Sq. cm.
Total area of median section	19.03
Area of neck alone..........	14.87
Area of back body..........	4.16

	Capacity of Cavity in Cu. cm.
Whole cavity...............	28.93
Front "Porch" or neck......	25.22
Back "belly" or body........	3.71

	cm.
Length of front neck........	8.
Diam. of opening front lip...	.7
Velar.....................	1.5
Epiglottis..................	.3
Larynx....................	.8

Fig. 184. Vowel ə (the). Subject 202.

cm.. (.5) .7 2.8 2.8 2.8 2. 1.3 1.2 1.0 (.3) .5 .8 .7 .6 .6 (.6)

Diameters of cavity in median section at intervals of one centimeter

	Sq. cm.
Total area of median section	15.69
Area of neck alone..........	13.34
Area of back body..........	2.35

	Capacity of Cavity in Cu. cm.
Whole cavity...............	20.75
Front "Porch" or neck......	19.41
Back "belly" or body........	1.34

	cm.
Length of front neck........	9.5
Diam. of opening front lip...	.5
Velar.....................	.3
Larynx....................	.6

Fig. 185. Vowel *o* (foam). Subject 202.

cm. 1.4 (1.2) 1.8 2.4 3.1 2.9 2.5 1.9 1.6 (.8)

1.7
.6
.7
1.5
.8
.7
(.5)

Diameters of cavity in median section at intervals of one centimeter

	Sq. cm.
Total area of median section	23.21
Area of neck alone..........	18.27
Area of back body..........	4.94

	Capacity of Cavity in Cu. cm.
Whole cavity...............	38.71
Front "Porch" or neck......	32.95
Back "belly" or body........	5.76

	cm.
Length of front neck........	8.5
Diam. of opening front lip...	1.2
Velar.....................	.8
Larynx...................	.5

Fig. 186. Vowel *ʊ* (foot). Subject 202.

(.4)

cm. .5 .5 .6 1.4 1.6 1.8 1.3 (2.1)

Diameters of cavity in median section at intervals of one centimeter

1.4 1.9 1.9 2. 1.3 (.4) .7 (.4)

	Sq. cm.
Total area of median section	16.68
Area of neck alone..........	7.68
Area of back body..........	9.00

	Capacity of Cavity in Cu. cm.
Whole cavity...............	23.70
Front "Porch" or neck......	11.53
Back "belly" or body........	12.17

	cm.
Length of front neck........	7.5
Diam. of opening front lip...	.4
Velar.....................	2.1
Epiglottis..................	.4
Larynx....................	.4

Fig. 187. Vowel *u* (fool). Subject 202.

cm. 1.1 (.4) 1. 2.6 1.1 0.3 0.4 (.3) 0.5 1.7

Diameters of cavity in median section 2.6 3.2 3.0 2.6 2.3 1.3 1.2 (.7)

at intervals of one centimeter

	Sq. cm.
Total area of median section	23.12
Area of neck alone..........	5.45
Area of back body..........	17.67

	Capacity of Cavity in Cu. cm.
Whole cavity	42.94
Front "Porch" or neck......	8.39
Back "belly" or body........	34.55

	cm.
Length of front neck........	7.
Diam. of opening front lip...	.4
Velar	.3
Larynx	.7

Fig. 188. Vowel *i* (peep). Subject 271.

cm. $(.^{6})$ $.^{7}$ $1.^{4}$ $3.^{9}$ $2.^{1}$ $1.^{8}$ $(1.^{1})$ $1.^{5}$

Diameters of cavity in median section at intervals of one centimeter

1. $2.^{4}$ $2.^{9}$ $2.^{2}$ $1.^{5}$ 1. $1.^{2}$ $1.^{4}$ $(.^{7})$

	Sq. cm.
Total area of median section	24.92
Area of neck alone..........	12.91
Area of back body..........	12.01

	Capacity of Cavity in Cu. cm.
Whole cavity...............	55.92
Front "Porch" or neck......	21.27
Back "belly" or body........	34.65

	cm.
Length of front neck........	8.
Diam. of opening front lip...	.6
Velar.....................	1.1
Larynx....................	.7

Fig. 189. Vowel *I* (pip). Subject 271.

(.9)

cm. 2.0 .8 1.7 1.7 1.5 .9 (.8) 1.2

Diameters of cavity in median section at intervals of one centimeter

2.6 2.5 2.4 2.1 2. 1.9

	Sq. cm.
Total area of median section	20.24
Area of neck alone..........	7.06
Area of back body..........	13.18

	Capacity of Cavity in Cu. cm.
Whole cavity...............	36.51
Front "Porch" or neck......	12.37
Back "belly" or body........	24.14

	cm.
Length of front neck........	7.3
Diam. of opening front lip...	.6
Velar.....................	.8
Larynx....................	—?

Fig. 190. Vowel *e* (pape). Subject 271.

cm.	2.1	(1.0)	1.4	2.7	2.5	1.9	1.3	(1.2)	1.5	1.3	2.8	2.5	2.2	1.8	1.9

Diameters of cavity in median section at intervals of one centimeter

	Sq. cm.
Total area of median section	22.47
Area of neck alone..........	10.19
Area of back body..........	12.28

	Capacity of Cavity in Cu. cm.
Whole cavity...............	37.49
Front "Porch" or neck......	15.95
Back "belly" or body........	21.54

	cm.
Length of front neck........	8.
Diam. of opening front lip...	1.
Velar.....................	1.2
Larynx...................	—?

Fig. 191. Vowel ɛ (pep). Subject 271.

cm. $(2.^{0})$ $2.^{4}$ $3.^{8}$ $3.^{5}$ $2.^{3}$ $1.^{8}$ $(1.^{7})$ $2.^{0}$ $1.^{3}$ $2.^{8}$ $2.^{0}$ $1.^{5}$ $1.^{3}$ $1.^{6}$ $1.^{3}$ $(.^{7})$

Diameters of cavity in median section at intervals of one centimeter

	Sq. cm.
Total area of median section	28.95
Area of neck alone..........	16.55
Area of back body..........	12.40

	Capacity of Cavity in Cu. cm.
Whole cavity...............	57.65
Front "Porch" or neck......	40.68
Back "belly" or body........	16.97

	cm.
Length of front neck........	8.
Diam. of opening front lip...	2.
Velar......................	1.7
Larynx....................	.7

Fig. 192. Vowel æ (pap). Subject 271.

cm. $(2.^{0})$ $2.^{5}$ $3.^{8}$ $5.^{2}$ $3.^{3}$ $2.^{3}$ $1.^{5}$ $(1.^{1})$ $1.^{2}$

$1.^{6}$ $1.^{1}$ $.^{9}$ $.^{9}$ $1.^{0}$ $.^{7}$ $1.^{6}$ $2.^{0}$ $(.^{6})$

Diameters of cavity in median section at intervals of one centimeter

	Sq. cm.
Total area of median section	27.10
Area of neck alone..........	20.30
Area of back body..........	6.8

	Capacity of Cavity in Cu. cm.
Whole cavity...............	67.44
Front "Porch" or neck......	56.90
Back "belly" or body	10.54

	cm.
Length of front neck........	9.
Diam. of opening front lip...	2.
Velar.....................	1.1
Larynx....................	.6

Fig. 193. Vowel *a* (balm). Subject 271.

cm. $2.^3$ $(1.^6)$ $3.^0$ $4.^5$ $5.^2$ $4.^5$ $2.^2$ $1.^0$ $.^6$ $(.^6)$

Diameters of cavity in median section at intervals of one centimeter

$.^6$ $.^7$ $.^4$ $.^4$ $(.^2)$ $.^3$ $.^6$ $1.^2$ $1.^9$ $(1.^1)$

	Sq. cm.
Total area of median section	30.87
Area of neck alone..........	25.35
Area of back body..........	5.52

	Capacity of Cavity in Cu. cm.
Whole cavity...............	76.44
Front "Porch" or neck......	71.21
Back "belly" or body........	5.23

	cm.
Length of front neck........	10.
Diam. of opening front lip...	1.6
Velar......................	.6
Epiglottis..................	.2
Larynx....................	1.1

Fig. 194. Vowel ɔ (paw). East U. S. Lady Subject 271.

cm. $1.^{4}$ $(.^{7})$ $1.^{1}$ $2.^{9}$ $4.^{3}$ $4.^{7}$ $2.^{4}$ $1.^{6}$ $1.^{0}$ $.^{9}$ $(.^{5})$

Diameters of cavity in median section at intervals of one centimeter

$.^{6}$ $.^{6}$ $.^{6}$ $.^{5}$ $.^{9}$ $1.^{6}$ $2.^{4}$ $(1.^{5})$

	Sq. cm.
Total area of median section	27.
Area of neck alone..........	20.70
Area of back body..........	6.30

	Capacity of Cavity in Cu. cm.
Whole cavity...............	57.22
Front "Porch" or neck......	49.03
Back "belly" or body........	8.19

	cm.
Length of front neck........	10.
Diam. of opening front lip...	.7
Velar......................	.5
Epiglottis..................	.4
Larynx.....................	1.5

Fig. 195. Vowel *o* (oh). East U. S. Lady Subject 271.

cm. 2.0 (1.7) 1.8 2.0 3.1 3.3 2.7 2.1 1.7 1.4 (.9) 1.2

Diameters of cavity in median section at intervals of one centimeter

1.7
1.3
1.1
(.8)
1.2
1.8
1.5
(.9)
1.8

	Sq. cm.
Total area of median section	29.90
Area of neck alone..........	19.15
Area or back body..........	10.75

	Capacity of Cavity in Cu. cm.
Whole cavity...............	51.98
Front "Porch" or neck......	38.98
Back "belly" or body........	13.

	cm.
Length of front neck........	9.5
Diam. of opening front lip...	1.7
Velar.....................	.9
Epiglottis..................	.8
Larynx....................	.9

Fig. 196. Vowel ə (the). Subject 271.

cm. 1.4 (.6) 1.2 2.9 2.1 1.8 1.4 .8 (.6) .7 1.2

Diameters of cavity in median section at intervals of one centimeter

.7 1.8 1.4 1.4 .9 .9 1.5 (1.0)

	Sq. cm.
Total area of median section	18.64
Area of neck alone..........	9.16
Area of back body..........	9.48

	Capacity of Cavity in Cu. cm.
Whole cavity...............	28.64
Front "Porch" or neck......	18.81
Back "belly" or body	9.83

	cm.
Length of front neck........	9.
Diam. of opening front lip...	.6
Velar.....................	.6
Larynx....................	1.0

Fig. 198. Vowel *U* (foot). Subject 271.

cm. (.2) $.^4$ $.^8$ $2.^2$ $4.^0$ $4.^7$ $2.^0$ $.^6$ $.^5$ $.^5$ (.2) $.^4$

Diameters of cavity in median section at intervals of one centimeter

$1.^0$ $1.^0$ $1.^5$ $1.^3$ $1.^5$ $(1.^3)$

	Sq. cm.
Total area of median section	21.88
Area of neck alone..........	15.52
Area of back body..........	6.36

	Capacity of Cavity in Cu. cm.
Whole cavity...............	46.82
Front "Porch" or neck......	39.08
Back "belly" or body........	7.74

	cm.
Length of front neck........	10.5
Diam. of opening from lip...	.2
Velar.....................	.2
Larynx....................	1.3

Fig. 199. Vowel *u* (moo). Subject 271.

cm. 1.2 (.8) 1.5 1.3 1.1 .8 (.9) .7 1.0 1.3 1.8

Diameters of cavity in median section at intervals of one centimeter

2.4
2.6
3.
3.5
3.4
3.2 (2.2)
3.0

	Sq. cm.
Total area of median section	30.90
Area of neck alone..........	10.65
Area of back body..........	20.25

	Capacity of Cavity in Cu. cm.
Whole cavity...............	61.43
Front "Porch" or neck......	8.25
Back "belly" or body........	53.18

	cm.
Length of front neck........	10.5
Diam. of opening front lip...	.9
Velar.....................	.6
Larynx...................	2.2

Fig. 214. *y* (müde). N. German Subject 392.
(with lip rounding)

($.^{7}$)

cm. $1.^{5}$ $1.^{1}$ $2.^{5}$ $1.^{6}$ $1.^{5}$ $1.^{1}$ $1.$ $1.^{4}$ ($1.^{4}$)

Diameters of cavity in median section at intervals of one centimeter

$2.^{8}$
$1.^{9}$
$2.^{7}$
$3.^{5}$
$4.^{2}$
$5.$
$5.^{3}$
$5.^{5}$
(2.)

	Sq. cm.
Total area of median section	36.70
Area of neck alone..........	11.26
Area of back body..........	25.44

	Capacity of Cavity in Cu. cm.
Whole cavity...............	111.46
Front "Porch" or neck......	17.
Back "belly" or body........	104.46

	cm.
Length of front neck........	9.
Diam. of opening front lip...	.7
Velar....................	1.4
Larynx...................	2.

Fig. 215. *y* (tür). N. German Subject 392.
(without lip rounding)

cm. (1.) $2.^{5}$ 4. $2.^{4}$ $1.^{8}$ $1.^{7}$ 2. $(1.^{5})$

Diameters of cavity in median section at intervals of one centimeter

$1.^{8}$
$3.^{1}$
$2.^{8}$
$2.^{6}$
$2.^{7}$
$2.^{7}$
$(1.^{7})$
$3.^{1}$
$2.^{5}$
$(1.^{4})$
$1.^{8}$

	Sq. cm.
Total area of median section	37.23
Area of neck alone..........	15.19
Area of back body..........	22.04

	Capacity of Cavity in Cu. cm.
Whole cavity...............	80.32
Front "Porch" or neck......	32.42
Back "belly" or body........	47.90

	cm.
Length of front neck........	8.5
Diam. of opening front lip...	1.
Velar.....................	1.5
Epiglottis..................	1.7
Larynx....................	1.4

Fig. 216. ø (möbel). N. German Subject 392.
(with lip rounding)

cm. (1.1) 1.3 1.5 1.7 1.7 1.8 1.7 2. (1.8)

Diameters of cavity in median section

1.2 2.9 2.7 2.8 3.0 3.0 2.7 3.2 (1.7)

at intervals of one centimeter

	Sq. cm.
Total area of median section	30.90
Area of neck alone..........	11.38
Area of back body..........	19.52

	Capacity of Cavity in Cu. cm.
Whole cavity...............	64.17
Front "Porch" or neck......	16.74
Back "belly" or body........	47.43

	cm.
Length of front neck........	9.
Diam. of opening front lip...	1.1
Velar.....................	1.8
Larynx....................	1.7

Fig. 217. ɸ (möbel). N. German Subject 392.
(without lip rounding)

cm. 1.9 (1.5) 1.6 1.6 2.2 2.1 1.5 2. 2. (1.6)

Diameters of cavity in median section

at intervals of one centimeter

3.4 3.1 2.9 2.8 3.2 (2.3) 3.6 4.1 (2.4)

	Sq. cm.
Total area of median section	37.90
Area of neck alone..........	13.71
Area of back body..........	24.19

	Capacity of Cavity in Cu. cm.
Whole cavity...............	89.34
Front "Porch" or neck......	24.12
Back "belly" or body........	65.22

	cm.
Length of front neck........	9.
Diam. of opening front lip...	1.5
Velar.....................	1.6
Epiglottis..................	2.3
Larynx....................	2.4

Fig. 218. Vowel *Y* (mütter). N. German Subject 392.
(lip rounding)

cm. $(1.^{4})$ $2.^{6}$ $4.^{3}$ $3.^{1}$ $2.^{6}$ $2.^{2}$ $2.^{3}$ $1.^{8}$ $(1.^{2})$

Diameters of cavity in median section at intervals of one centimeter

$2.^{2}$ $2.^{3}$ $1.^{9}$ $1.^{9}$ $2.^{3}$ $2.^{9}$ $(2.^{0})$ $3.^{1}$ $3.$ $(1.^{8})$

	Sq. cm.
Total area of median section	37.97
Area of neck alone..........	19.39
Area of back body..........	18.58

	Capacity of Cavity in Cu. cm.
Whole cavity...............	82.68
Front "Porch" or neck......	60.84
Back "belly" or body........	21.84

	cm.
Length of front neck........	9.
Diam. of opening front lip...	1.4
Velar.....................	1.2
Epiglottis..................	2.
Larynx....................	1.8

Fig. 219. *œ* (wölben). N. German Subject 392.
(lip rounding)

cm. ($2.^{1}$) $2.^{5}$ $1.^{1}$ $1.^{0}$ $.^{7}$ ($.^{5}$) $.^{7}$ $1.^{2}$

Diameters of cavity in median section at intervals of one centimeter

$.^{8}$ 1. $2.^{4}$ $2.^{6}$ 3. $3.^{6}$ $4.^{1}$ $3.^{8}$ $3.^{6}$ (2.)

	Sq. cm.
Total area of median section	29.85
Area of neck alone..........	8.47
Area of back body..........	21.38

	Capacity of Cavity in Cu. cm.
Whole cavity...............	70.20
Front "Porch" or neck......	11.05
Back "belly" or body........	59.15

	cm.
Length of front neck........	8.5
Diam. of opening front lip...	2.1
Velar.....................	.5
Larynx....................	2.

Fig. 220. Vowel *i* (biete). N. German Subject 392.

Diameters of cavity in median section at intervals of one centimeter

cm. .8 2.1 1.2 1.2 1. .9 1.0 (.7)

.8 1.1 2.0 2.0 2.2 2.4 2.2 2.8 (1.9)

	Sq. cm.
Total area of median section	22.26
Area of neck alone..........	8.66
Area of back body..........	13.60

	Capacity of Cavity in Cu. cm.
Whole cavity...............	34.40
Front "Porch" or neck......	8.43
Back "belly" or body........	25.97

	cm.
Length of front neck........	8.
Diam. of opening front lip...	.8
Velar.....................	.7
Larynx....................	1.9

Fig. 221. Vowel *ɪ* (bitte). N. German Subject 392.

cm. $1.^{8}$ $(1.^{4})$ $2.^{3}$ $1.^{4}$ $1.$ $1.$ $1.$ $(1.)$ $1.^{2}$ $1.^{4}$ $2.^{2}$ $2.^{4}$ $2.^{8}$ $2.^{4}$ $2.^{7}$ $(1.^{6})$

Diameters of cavity in median section at intervals of one centimeter

	Sq. cm.
Total area of median section	25.23
Of mouth alone.............	10.31
Of throat alone.............	14.92

	Capacity of Cavity in Cu. cm.
Whole cavity...............	40.35
Front mouth...............	12.92
Back throat...............	27.43

	cm.
Length of front tube........	9.
Diam. of front lip opening...	1.4
Diam. of velar opening......	1.
Diam. of larynx opening.....	1.6

Fig. 222. Vowel *e* (beten). N. German Subject 392

cm. 1.4 (1.1) 1.3 1.7 1.8 1.9 2.1 2.2 2. (1.5) 2.7 2.5 2.4 2.4 2.7 3. (.9)

Diameters of cavity in median section at intervals of one centimeter

	Sq. cm.
Total area of median section	29.86
Median sec. area mouth alone	15.28
Of back throat alone........	14.68

	Capacity of Cavity in Cu. cm.
Whole cavity...............	55.60
Front mouth...............	22.56
Back throat...............	33.04

	cm.
Length of palatal tube.......	9.
Diam. of lip opening........	1.1
Diam. of velar opening......	1.5
Diam. of larynx opening.....	.9

Fig. 223. Vowel ɛ (bett). N. German Subject 392

cm. (1.6) 2.1 2.4 2.7 1.5 2.8 (1.3)

Diameters of cavity in median section at intervals of one centimeter

1.4 2.3 1.8 1.7 1.2 (.9) 1.1 (.8)

	Sq. cm.
Total area of median section	22.70
Area of neck alone..........	13.94
Area of back body..........	8.76

	Capacity of Cavity in Cu. cm.
Whole cavity...............	39.70
Front "Porch" or neck......	27.14
Back "belly" or body........	12.56

	cm.
Length of front neck........	8.5
Diam. of opening front lip...	1.6
Velar.....................	1.3
Epiglottis..................	.9
Larynx....................	.8

Fig. 224. Vowel a (bat). N. German Subject 392.

cm. (2.2) 2.5 3.1 3.6 3.8 3.3 2.1 1.5 (.9) .8 .7 (.6) .9 .8 1.4 (.8)

Diameters of cavity in median section at intervals of one centimeter

	Sq. cm.
Total area of median section	24.81
Area of neck alone..........	20.47
Area of back body..........	4.34

	Capacity of Cavity in Cu. cm.
Whole cavity...............	55.77
Front "Porch" or neck......	51.93
Back "belly" or body........	3.84

	cm.
Length of front neck........	9.5
Diam. of opening front lip...	2.2
Velar....................	.6
Epiglottis.................	.6
Larynx...................	.8

Fig. 225. Vowel *a* (vater). N. German Subject 392.

cm. $1.^6$ $(1.^0)$ $1.^6$ $1.^9$ $3.^8$ $4.^0$ $3.^6$ $2.^4$ $1.^8$ $(0.^4)$

Diameters of cavity in median section at intervals of one centimeter

$1.^0$ $0.^5$ $(0.^3)$ $0.^8$ $0.^8$ $(0.^6)$

	Sq. cm.
Total area of median section	24.29
Median area of front palatal.	20.58
Median area of back throat. .	3.71

	Capacity of Cavity in Cu. cm.
Whole vocal cavity..........	48.15
Front palatal cavity only....	45.70
Back throat cavity only......	2.45

	cm.
Length of front mouth tube. .	9.5
Diam. of front lip opening. . .	1.
Diam. of velar aperture.....	0.4
Diam. of pharynx opening. . .	0.3
Diam. of larynx opening.....	0.6

Fig. 226. Vowel ɔ (Sonne). N. German Subject 392

cm. (1.^{8}) 1.^{3} 2.^{1} 3.^{1} 3.^{3} 3.^{1} 2.^{5} 2.^{3} (1.^{4})

Diameters of cavity in median section at intervals of one centimeter

1.^{0}
1.^{2}
1.^{0}
(.^{9})
1.^{3}
1.^{3}
(1.^{4})

	Sq. cm.
Total area of median section	26.89
Area of neck alone..........	21.76
Area of back body..........	5.13

	Capacity of Cavity in Cu. cm.
Whole cavity...............	47.49
Front "Porch" or neck......	41.50
Back "belly" or body........	5.99

	cm.
Length of front neck........	9.5
Diam. of opening front lip...	1.8
Velar.....................	1.4
Epiglottis.................	.9
Larynx....................	1.4

Fig. 227. Vowel ə (manne). N. German Subject 392.

cm. (.8) 1.6 1.9 2.9 3.4 3.1 3.0 2.0 1.7 (.4) .8 .8 .4 (.4) .8 1.3 1.6 (1.1)

Diameters of cavity in median section at intervals of one centimeter

	Sq. cm.
Total area of median section	26.
Area of neck alone..........	21.32
Area of back body..........	4.68

	Capacity of Cavity in Cu. cm.
Whole cavity...............	48.97
Front "Porch" or neck......	44.51
Back "belly" or body........	4.46

	cm.
Length of frone neck........	9.5
Diam. of opening front lip...	.8
Velar....................	.4
Epiglottis.................	.4
Larynx....................	1.1

Fig. 228. Vowel *o* (mohn). N. German Subject 392.

cm. (.2) .3 1.0 2.8 4.2 2.8 2.8 1.8 .5 .6 (.2)

Diameters of cavity in median section at intervals of one centimeter

.2 .9 1.0 1.4 2.9 3.5 (2.7)

	Sq. cm.
Total area of median section	24.03
Area of neck alone..........	14.53
Area of back body..........	9.50

	Capacity of Cavity in Cu. cm.
Whole cavity...............	55.26
Front "Porch" or neck......	36.16
Back "belly" or body........	19.10

	cm.
Length of front neck........	10.
Diam. of opening front lip...	.2
Velar.....................	.2
Larynx....................	2.7

Fig. 229. Vowel *u* (mut) German Subject 392.

NOTES
CORRECTIONS AND COMPUTATIONS
BY READER

CHAPTER XII

TONGUE POSITION IN VOWELS AS SHOWN BY X-RAYS

"Each new position of the tongue produces a new vowel. . . It is necessary therefore to select certain definite fixed points to serve as marks, as it were, of latitude and longitude, whence the intermediate positions can be measured and defined with more or less minuteness.

"The horizontal movements of the tongue produce two well-marked classes of vowels; 'back' such as *a*, *ɔ*, *ᴜ*, and "front' such as *i*, *ϵ*, *æ*. In the former the tongue is retracted into the back of the mouth, and its fore part is pressed down, so that the tongue slopes down from the back to the front of the mouth. . .

"The vertical movements of the tongue . . . produce various degree of height or distance of the tongue from the palate. In a 'high' vowel such as *ɪ* . . . the front of the tongue is raised as high and as close to the palate as is possible without causing audible friction; while if it is lowered as much as possible from this position without otherwise altering the relative position of tongue and palate, we obtain the corresponding 'low' vowel. Thus *æ* is a low-front, *ɔ* a low-back, and *ə* a low-mixed vowel. If the tongue stops exactly half-way, we obtain the normal 'mid' position, as in the first elements of of *ei* and *ou*, which are mid-front and mid-back respectively.

"In this way the whole mouth may be mapped out schematically into nine squares: —

narrow wide	high-back (*u*—F. sou) (*ᴜ*—E. good)	high-mixed	high-front (*i*—F. si) (*ɪ*—E. it)	narrow wide
narrow wide	mid-back (*o*—F. beau) (*O*—E. oil)	mid-mixed (*ə*—E. sofa)[3]	mid-front (e—F. eté) (*ϵ*—E. ten)	narrow wide[2]
narrow wide	low-back (*ɔ*—E. all) (*ɔ*—E. October[2]	low-mixed (*ə*—E. sir)[3]	low-front (*æ*—E. air) (*Æ*—E. at)	narrow wide

"The connexion between the size and shape of the resonance-chamber and the pitch is clear enough in the case of these vowels. *i* owes its high pitch to its being formed by a very narrow short passage in the front of the mouth. In *ɪ* the flattening of the tongue lengthens and widens the passage, and consequently dulls the sound. It is still more dulled in *e*, in whose formation the whole body of the tongue is lowered. In fact, in the series *i*, *ɪ*, *e*, *ϵ*, *æ*, *Æ*, there is progressive widening of the configurative passage."

— Sweet[1] (1910)

Let us divide the mouth cavities of our stereographic set of X-rays, in accordance with Sweet's scheme, "into nine squares." We can set off the area from the Wisdom Tooth (or in other words the beginning of the Soft Palate) to the Pharyngeal wall as the "back" tier of squares; the "front" group can begin at the upper teeth, and run to a perpendicular line drawn half way between there and the Wisdom Tooth; and his "mixed" trio will then be formed by the space

[1] SWEET, Henry. *The Sounds of English.* (1910) Oxford Press 2nd ed. Quotation taken from p. 24, 25, paragraphs 54, part of 55, and the table from 56. The examples in parentheses are taken from paragraphs 64 and 78, except where otherwise indicated. The symbols are transposed to those used herein.

[2] *Idib.* Examples in parentheses taken from pages 72 and 73.

[3] *Ibid.* Examples taken from his page 71.

between these two. We now have three columns which appear thus:

Back	Mixed	Front

For the vertical division we can fix the lower horizontal line at a point just below the position of the tongue for *a* (ah), which in this one case happens to conform to the tradition as the lowest of the vowels;[2] and the upper line can parallel that of the Palate or roof of the mouth; to make the division into three rows of squares, all we need do then is to draw two lines in between these at such points as to divide the space in three equal parts. Our scheme shows now as it appears in Fig. 230-a.

Thus we divide the buccal cavity into "nine equal boxes." The upper row of three squares counting from front to back, stand for Sweet's "high" series including as the: 1st box, the high-front (hf); 2d, high-mixed (hx); and 3d, high-back (hb). The middle string of three boxes will in the same manner stand for his "mid" group: 1st, mid-front (mf); 2d, mid-mixed (mx); 3d, mid-back (mb). And the lower line of three squares will represent his "low": 1st, low-front (lf); 2d, low-mixed (lx); 3d, low-back (lb).

This nine square diagram has been drawn to scale so as to conform to the stereographic set of vowel cavities published herein. It is printed on transparent paper (Fig. 230-a) so that the reader can detach the same and place it over each stereographic X-ray picture and make the measurements or classification for himself. Adjust it so that the front side of the scheme rests at the tip of the upper marker, and the top edge corresponds with the arched palate line, and the back side runs parallel with the pharynegeal or throat wall.

Care need only be taken to be sure it is always placed in the same relative position. We are thus provided with Sweet's scheme for the indication of tongue-arching in accordance with certain lines of "latitude and longitude."

The division of the globe on which we live, into such sections, makes it possible for us to describe the location of a given object in a minutely accurate way. But the object must occupy a rather small speck-like space compared with the section of lattitude and longitude in which it falls. If the moon fell onto the globe, it would not be so easy to state the location; for it would cover too large an area. The best we could do would be to say it was bounded on one side by this degree and on the other by that. So we may be justified in concluding that Sweet conceived of the point of tongue-arching as being rather sharply delineated in some sort of an apex which could easily be located in one of those "longitude-lattitude" boxes.

The first thing we note is that the space covered by the tongue arch is so large in relationship to the scheme, that it presents the same difficulty of description, we would encounter in locating the above mentioned moon, or a continent on the globe, in terms of lattitude and longitude. We see that the tongue does not take those traditional sharply arched humps. We have commented on that fact in the chapter on the Tongue-Arching Vowel Triangle—a Fallacy. So, for example, we see that the *i* does not arch up towards the alveolar ridge in the high-front (hf) box and from there drop abruptly back and downward toward the larynx. And we observe that in the *u* the tongue is **not** here

> "retracted into the back of the mouth, and its fore part pressed down, so that the tongue slopes down from the back to the front of the mouth"

thus providing a sharp hump which could be located in the high-back (hb) square as Sweet would have had it.

Actually, this subject has taken a front position for *u* (boom) which follows a line almost identically the same as that of the ɛ (pep) so far as the front cavity is concerned; and it varies but very little at that point from that of the *æ* (pap) or the *ɪ* (pip), none of which differ materially from each other. All those front vowels (except the *æ*) drop abruptly on an almost perpendicular line toward the larynx, and so does the *u* (oo) in this particular case.

We see at once that all the so-called "front" vowels continue their arching back to the point where the Hard and Soft Palates join; and they do not begin to drop towards the larynx until the tongue is well back in the neighborhood of the "back" tier of boxes. If therefore we were to describe the vowels of the subject we have before us in terms of Sweet's classification, we would have to consider more than the one box he contemplated as being involved in the arching.

The point of arching for all these would-be "front" vowels extends along the tongue well back into the "high-mixed" square. The *i* shows a cavity which is much more closed than is common to most individuals, and since this subject has a peculiar back and downsloping palate, the tongue which in this case presses up tightly against the hard palate (following its arch quite precisely) shows for the *i* about the only decided apex which is to be found. But even here the arch follows well past that point into the "high-mixed" box.

So that all so-called "front" vowels would have to be classified as "mixed" instead, if we took the point in their tongue-arching where it began to slope downwards toward the larynx. And for this stereographic

series, they would run in their progressive order from the most closed to the most open, as follows:

i, e, u, ɪ, æ, ɛ;

or to designate them by the traditional hump in the Sweet classification;

i (high-mixed)	*e* high-mixed)	*ɪ* (high-mixed)
u (mid-back)	*ɛ* (high mixed)	*æ* (mid-mixed)

It will be noticed that the two do not agree at all, for the simple reason that the point where the tongue begins to slope most abruptly towards the larynx, is not the point of narrowest opening.

If we took this point of narrowest opening for our criterion, they would range thus:

i (high-mixed?)	*e* (high-mixed)	*u* (mid-back?)
ɪ (high-front)	*ɛ* (mid-mixed)	*æ* (mid-mixed)

Tomás Navarro Tomás suggests the process he has been accustomed to use, namely, lay a ruler horizontally across the group of tongue arches, and take the point of highest apex as it appears above the horizontal edge, which would give something like this:

i (high-front)	*e* (high-mixed)	*ɪ* (high-front-mixed)
ɛ (high-front?)	*æ* (high-mixed?)	*u* (high-mixed)

What agreement is there? Which will the reader choose? Of what value will it be after he has chosen it? Do any of them bear upon the question as to what causes differences in vowel quality? If so, how?

If the Palate represented a regular flat ceiling, which it does not, the latter would give both the length of the front tube, and the diameter of the back opening each

of which are vital factors in changing the pitch of a pipe. But since the palate is irregular, how shall we use the classification once we make it?

A measurement of the narrowest point from the Palate would avoid any such objection. But even in this case it would be far more accurate to use a millimeter measurement from the front aperture of the tube to that point of narrowest opening. For it is the length of the organ pipe which is primarily responsible for its pitch. No physicist, however, would use such a measurement for length; he would be very likely to take the total length of the pipe from end to end, regardless of any slight constriction or indentation someplace in the middle. Such a measurement as the one indicated, could therefore be entirely misleading if we proposed to use it in showing the effective length of the tube. And it would be entirely insufficient if we conceived of this front cavity as functioning like a spherical or irregular resonator whose pitch is governed by its total volume and size of openings rather than length. In that case, the diameter would of course be all important. Otherwise it is of less importance than the length.

In any event, a computation of the diameter at only one point along that center line, is woefully inadequate. Even for approximate purposes, if we are to be provided with the information we need in regard to the diameter of the tube, measurements must be made of not only one, but rather a number of points along the median, and these spaced at regular intervals. E. A. Meyer recognized that fact and proposed measurements at 1 cm. intervals, the average of a given number of which, he used as a criterion in his plastographic experiments. It is this fact which Viëtor refers to in the quotation with which we began our chapter herein

on The Tongue-Arching Vowel Triangle—a Fallacy. As he says, one point of arching tells us practically nothing. And that is apparently the principal reason why he was led to disown his pet child — the tongue-arching vowel triangle, for whose present wide use he is so largely responsible.

Of course, there never was any sense in considering a point of highest arching as a vital factor in causing changes of vowel quality, except as that point might be involved in some such theory as that last enunciated by Sweet in the quotation with which we began this chapter, viz.

> "*ị* owes its high pitch to its being formed by a **very narrow short passage in the front of the mouth.**"[1]

That conceives of the cavity tone which characterizes the (whispered) vowel as being governed by the same law as that involved in the pitch of organ pipes. This we might state in two parts, disregarding[2] for the moment as he did, the function of the lips, openings and other factors, to-wit:

(a) The shorter the pipe the higher the pitch.
(b) The longer the pipe the lower the pitch.

It is evident that if the tongue did make a sharp hump in his hf box in the neighborhood of the alveolar ridge for the production of *i*, a short pipe about 2.5 cm (or roughly 1 inch) long would be created between there and the teeth. If governed by the same law as that for open pipes it would produce a tone with a wave of air twice as long as the tube.[2] According to Ellis, and Helmholtz (who use middle c_1=264 double

[1] SWEET, Henry. *Sounds of English.* 2nd ed. (1910) Oxford Press. p. 31, paragraph 76. Blackface type mine.

[2] *Sensations of Tone,* 4 ed. Longmans Green (1912) p. 22, 26, and 88. Our computation is but approximate also, because not mathematically exact, and we disregard the effect surfaces, force of air pressure, temperature of air, etc., might have on its pitch.

vibrations per second) a pipe producing c_1 has a wave length of 4 feet. This would give a 2¼-inch wave length (one somewhat longer than that corresponding to this length tube, which would only be 2 inches long) a pitch of 5.808 d. v./sec. a tone at least an octave above the pitch cited by Sir Richard Paget[1] for *i* (i. e. one between 2298 and 2579 d. v./sec; or the mean high frequency given by Crandall 2987, 3266.)[2] But the coupling on of a low-pitched back cavity might lower the tone of the front buccal cavity sufficiently to bring the latter within the range of these acoustic requirements.

So of course it becomes evident that both Sweet's scheme and the triangle are shown to be out of harmony with the facts, but if his conclusion in regard to tongue arching had been shown to be true by X-ray examination there would have been some justification for classifying the vowel *i* (ee) as high-front narrow as has been customary among certain groups since his day. For if the tongue did arch in that (hf) box, the cavity would be short and possibly responsible for one of the important elements involved in vowel quality. But unfortunately this aspect of the theory is not substantiated by the facts; for the tongue is discovered to arch back far beyond that point. So the whole scheme breaks down.

If Sweet's theory had been sustained by X-ray analyses which show the actual tongue arching, we would have had to acknowledge his scheme to have some interpretative value for the other vowels in the series too.

[1] PAGET, Sir Richard. *The Production of Artificial Vowel Sounds.* Proc. Roy. Soc. A. Vol. 102, (1923) p. 753. (cf. also his letter of Mar. 3, 1922, to Nature No. 2733, Vol. 109, p. 341 et seq.)

[2] CRANDALL, Irving B. *The Sounds of Speech,* Bell Technical Jour. Nov. 1925, p. 611.

The *u* could have been said to manifest the characteristic low-pitched cavity tone (which we know to be present in its quality components) principally because of the long mouth tube. For the *u* was supposed to arch way back in the rear of the mouth giving thus a tube many times as long as that of the *i* and producing a correspondingly low pitch. We know that a long organ pipe is characterized by a low pitch. But frequency components have been cited for *u* (fool) varying in wave length all the way from 3¼ to 1¼ feet. Since the lip closure may be great, the cavity then approximates that of a closed organ pipe, and this vowel might then have a cavity tone whose wave of air would be as much as four times as long as the tube. And the mouth makes possible a front tube 4 or 5 inches long as a maximum. This would therefore give a wave length of from 1 1/3 to 1 2/3 feet. But most thinking scientists would be likely to maintain that a cavity of the irregular type he postulates here would have a natural period of frequency which would be more likely to be governed by the laws for spherical resonators than those for organ pipes and even this wave might be thus lengthened and pitch lowered, thereby more nearly approximating the analyzed wave length of 3¼ feet which some have found present in the recorded speech curve. In any event, we might see a real theoretical reason for classifying *u* (pool) as a high-back vowel, if the tongue did so arch, and the resulting front cavity tone were the most vital factor in causing its quality, which proves not to be the case.

For, as the reader can see for himself, the tongue does not follow the theoretical arching scheme for *u* (oo) either. As we indicated above,

the tongue is not

"retracted into the back of the mouth, and its fore part

pressed down, so that the tongue slopes down from the back to the front of the mouth. . ."

as Sweet would have had it. And it does not necessarily have to manifest that sharp hump back there in the high-back box, which both his scheme and that of the vowel triangle required.

On the other hand, this stereographic set, does show an *a* (ah) with a tongue position which lies flattest in the mouth. However, it is evident that such a manifestation is purely incidental, and without importance in the creation of the quality which characterizes this vowel. For Fig. 263 shows a production with an arching of the tongue right in the center, and that with a position much higher up than was formerly postulated for an ə (uh). And Fig. 34 showing a life size X-ray photograph of a very loudly prolonged *a* (ah) by another subject, a lady, shows a high-back arching of the tongue, which formerly almost anybody would have designated as that representative of an *u* (who). As a matter of fact, this is one of the vowels which may be produced with almost any kind of a front tongue position the subject may desire to take. And there is certainly no justification whatever, for giving it any classification which would indicate its quality as due to either a low-front, low-mixed, or low-back position. About the only characteristic physiological manifestation which it shows as a more or less universal constant, is its constricted opening in the neighborhood of the epiglottis. The fact that the tongue ever lies flat in the mouth, or the jaws are wide open, or the lips spread wide apart, would seem to serve primarily, only to provide a better horn-like megaphone, in order to give it its characteristic as one of the loudest of our vowels, with the least modification of the partials or tonal quality produced by the vocal cords, or in the glottal note.

When we turn now to the consideration of the tongue position which the X-ray shows to be actually taken in the production of the other vowels, we find quite as little proof for traditional conceptions.

The *Æ* (at) which Sweet classified as low-front-wide, and which Bell spoke of as being due to

"the *enlargement* of the formative aperture caused by the *depression* of the *middle* of the tongue *backwards*."

turns out to regularly manifest characteristics which are diametrically the opposite. For as it appears in Fig. 262 it quite commonly shows

a *narrowing* of the formative aperture caused by the *arching* of the *middle* of the tongue *forwards*.

And though the vowel tongue position shown in the stereographic set does not manifest quite so decided a hump, it follows generally the same description.

However, this much may be said, that while this type of tongue position is the rule, it does not seem to be required in order to produce the vowel. For as the reader may prove, to his own satisfaction, it is possible to press the tongue, with the index finger, flat down in the mouth to its lowest position and still produce a perfectly good *Æ* (pap). So there must be some other reason for the quality manifest in this vowel. And the front tongue position can only be considered as contributory, at best.

Now we come to the pairs of front vowels, ε (pep), *e* (frame); and ɪ (pip), *i* (peep). These we can deal with more in detail in the chapter on open and close vowels. The fact that the tongue arches for all of them way back to the point of articulation for *K*, has been noted above. This is anything but confirmation of the traditional view.

FIG. 230. Vowel i (peep) Mid-East American. Male. Cultured but non-pedantic pronunciation. Normal unimpeded speech. Note the size of the back throat cavity. Also position of the epiglottis as well as Velum and front Mouth.

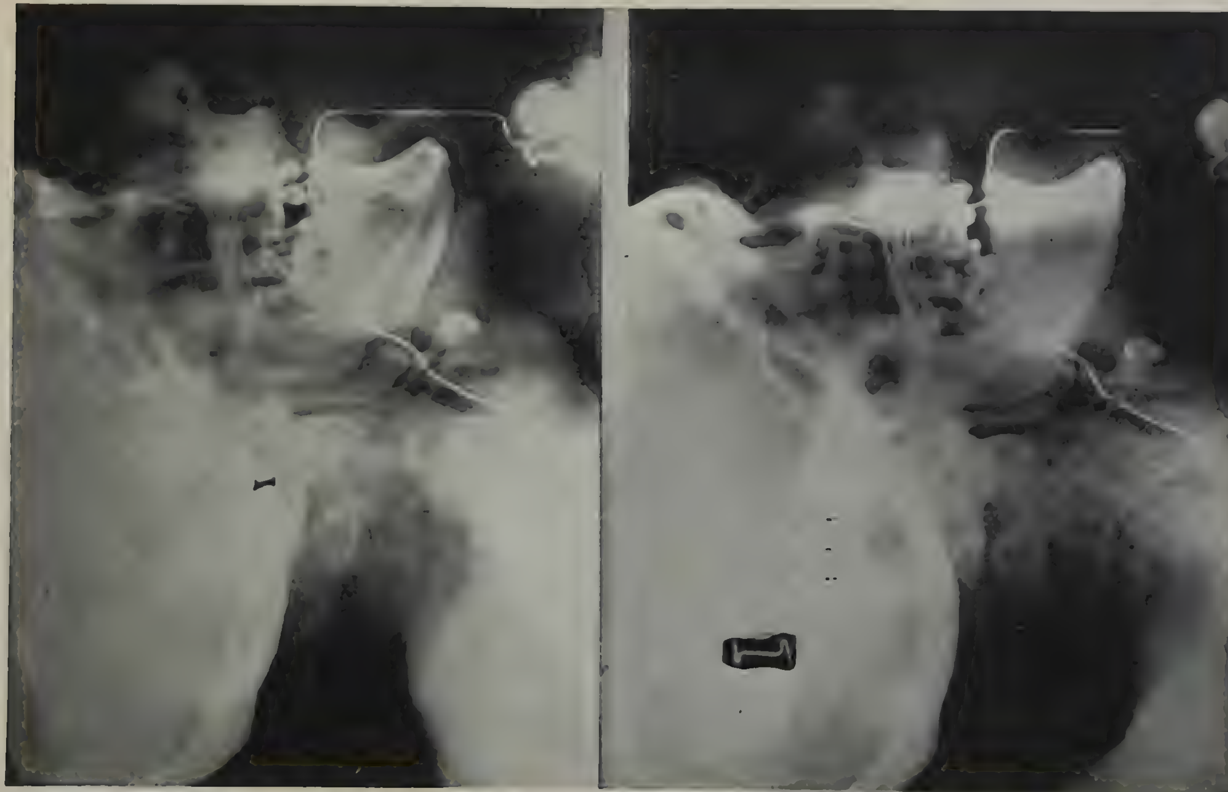


FIG. 231. Vowel *ɪ* (pip) Same subject as Fig. 230. By looking fixedly at the Hyoid Bone or Teeth thru a stereograph for some time all the organs in the head will begin to assume their proper respective proportions and perspective.

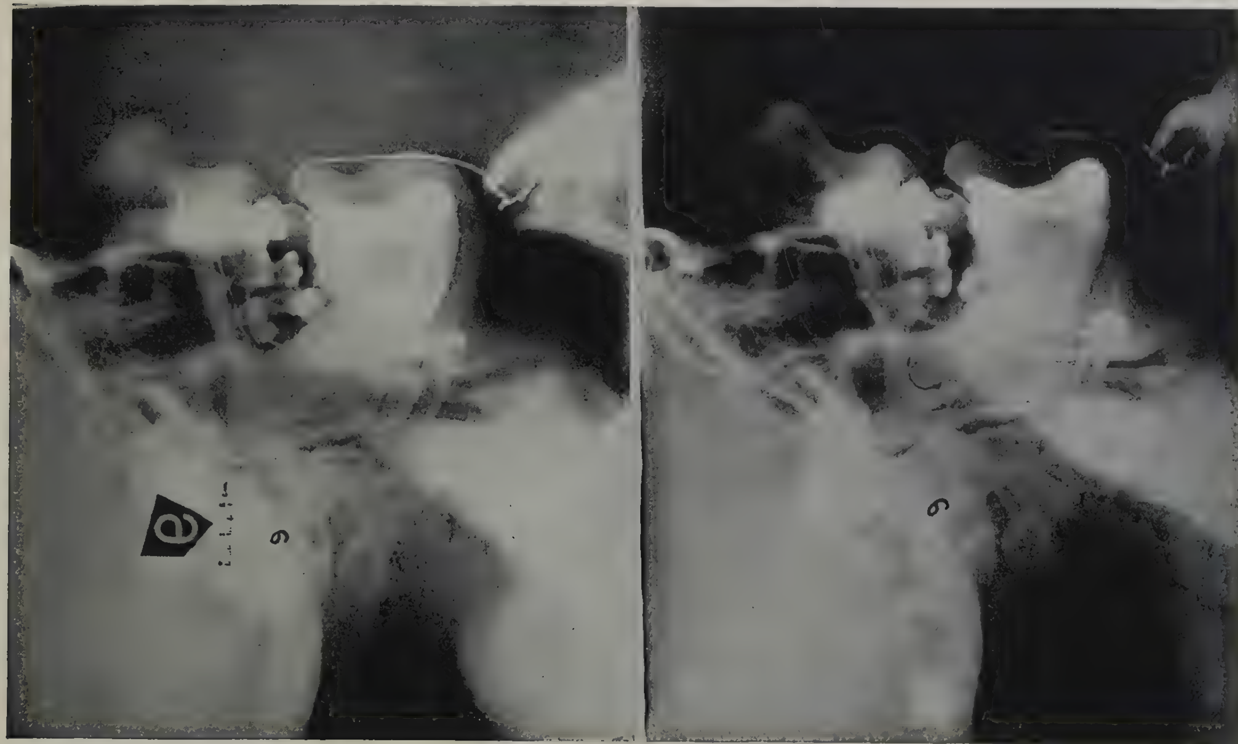


FIG. 232. Vowel *e* (fame) Same subject as Fig. 230. Note how much more closed the front palatal cavity is than for *ɪ* (pip) of Fig. 231. The throat cavity is also more distended, and the Epiglottis opening closes more.

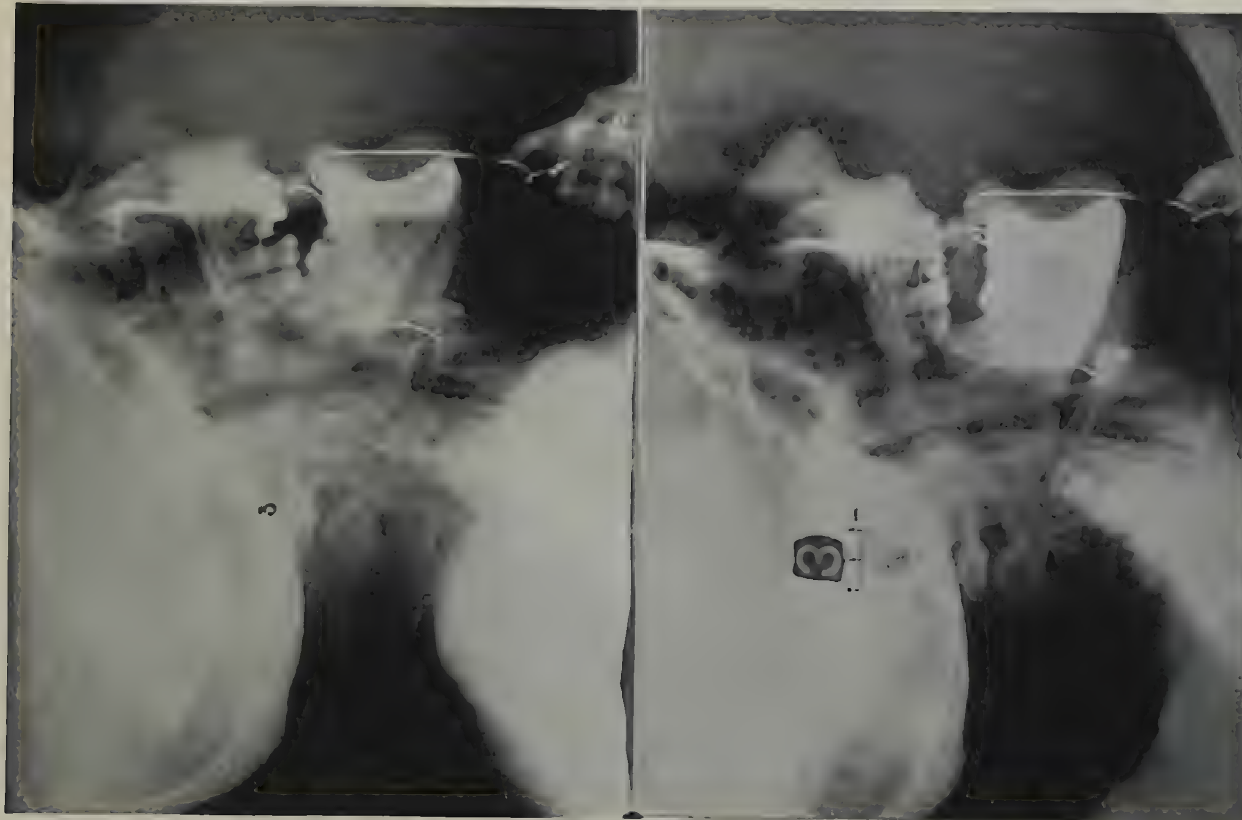


Fig. 233. Vowel ɛ (pep) Same subject as Fig. 230. All pitches 100 d. v./sec. We notice that the lip corner spread is greater than for the preceding. The front palatal cavity is not materially more open than for Fig. 231 for ɪ (pip). But compare the Hyoid muscle tension.

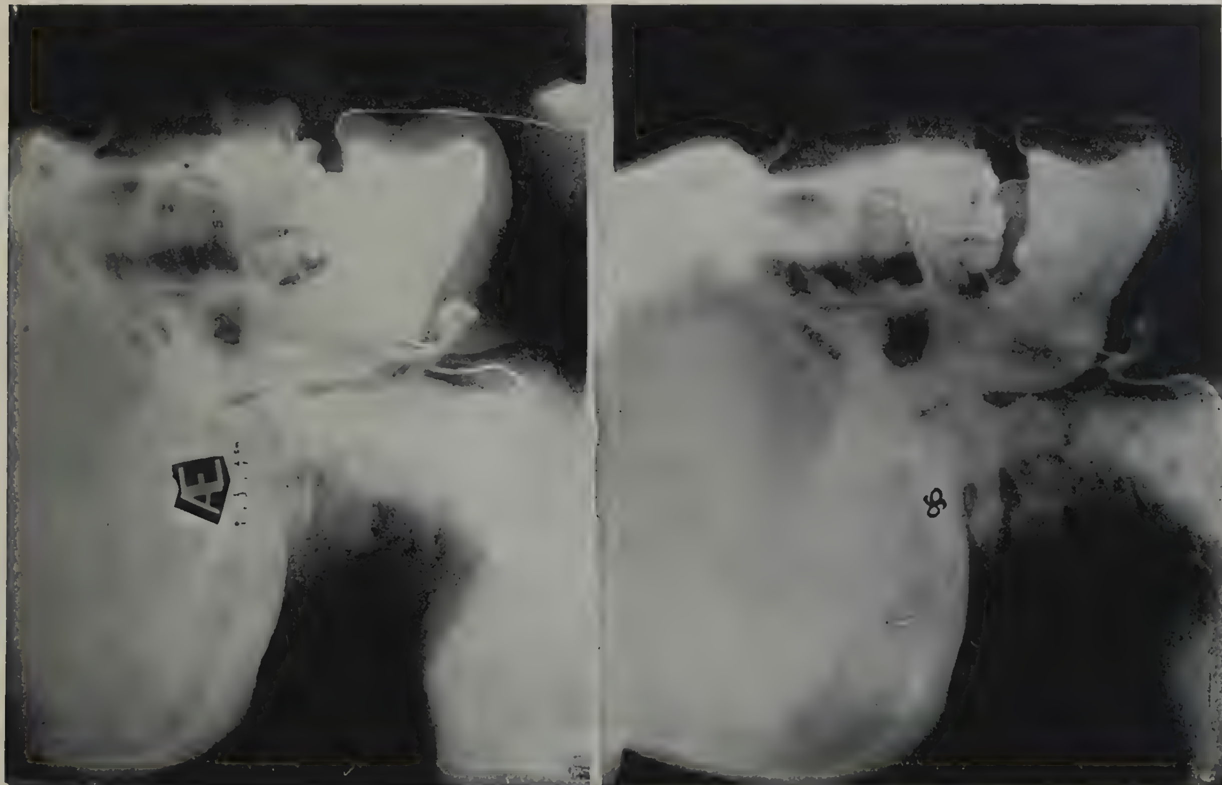


FIG. 234. Vowel æ (pap) Same subject as Fig. 230. Front cavity essentially the same size as for ɛ (pep) or even ɪ (pip) of Figs. 233 and 231. A radical shift in the position of the Epiglottis takes place however, making this a transitional vowel.

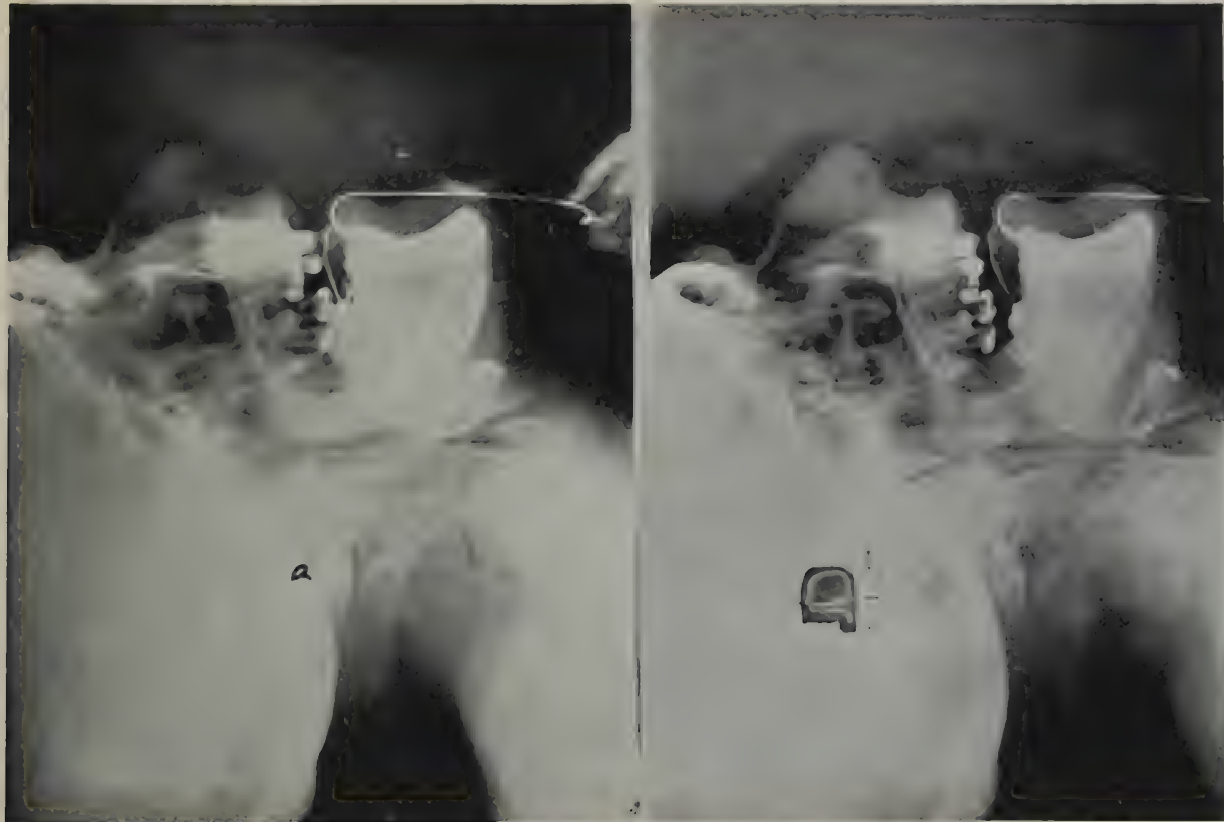


FIG. 235. Vowel *a* (ah) Same subject as Fig. 230. Epiglottis opening shows the usual most characteristic closure. And while the front cavity is here wide open and tongue flat, it need not be. The back throat constriction seems to be the only fixed characteristic.

FIG. 236. Vowel ɔ (aw) Same subject as Fig. 230. More soft surfaces appear to be involved in the constriction of the soft tongue creating a longer soft-surface opening up towards the palatine arches, thus making the vowel quality more "dead" than for *a* (ah).

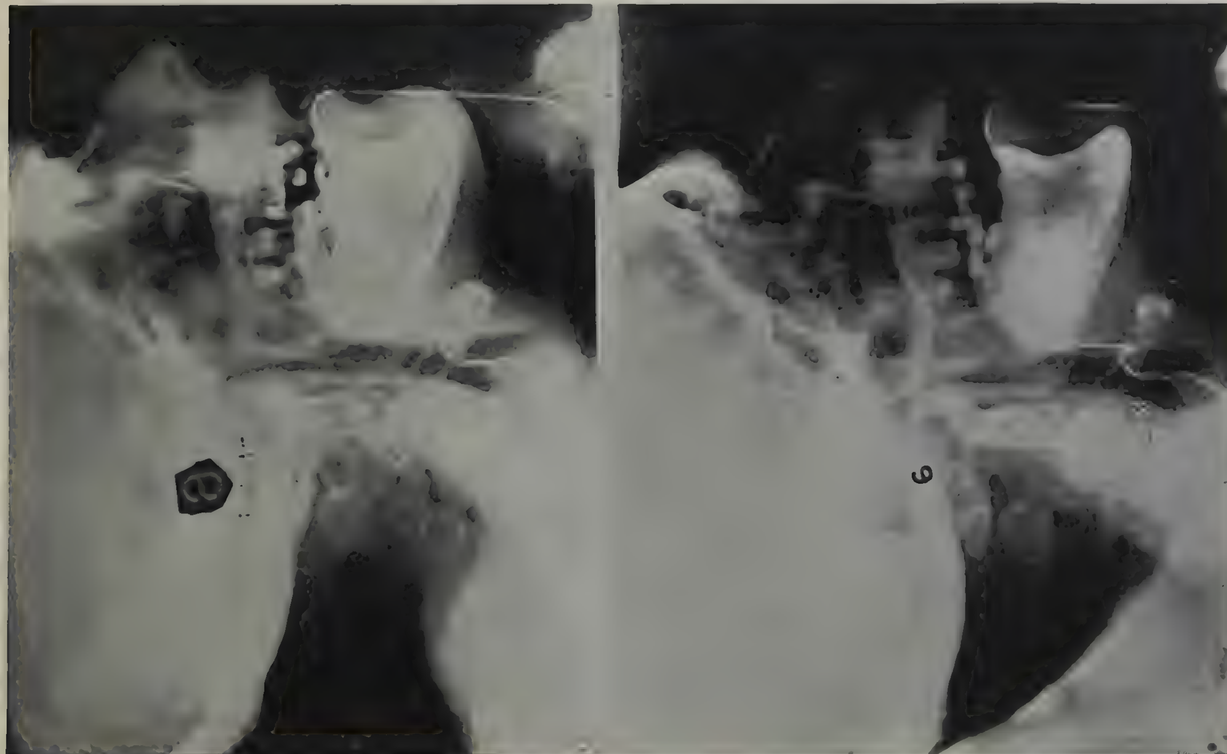


FIG. 237. Vowel ə (uh) Same subject as Fig. 230. It will be noted that both the front and back cavity, and epiglottis opening are not distended, making of this vowel another pivotal one in a series. We have thus, *i* (ee), *a* (ah), ɔ (uh), and *u* (oo) as pivotal vowels.

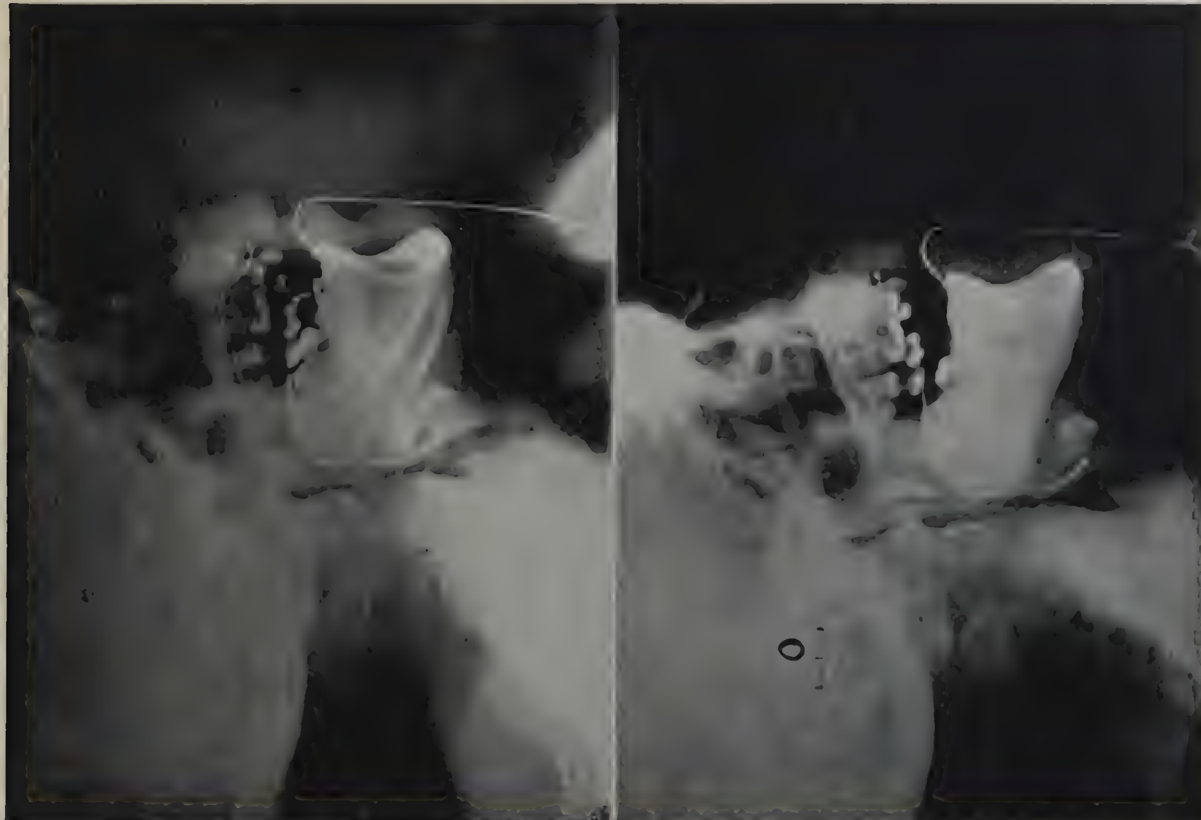


FIG. 238. Vowel o (oh) Same subjects as Fig. 230. This vowel partakes more of the quality and position for ɔ (aw) than ə (uh), in that the soft surfaces back in the throat again close up. A lower laryngeal resonator also begins to be manifest, thus tending toward u (oo).

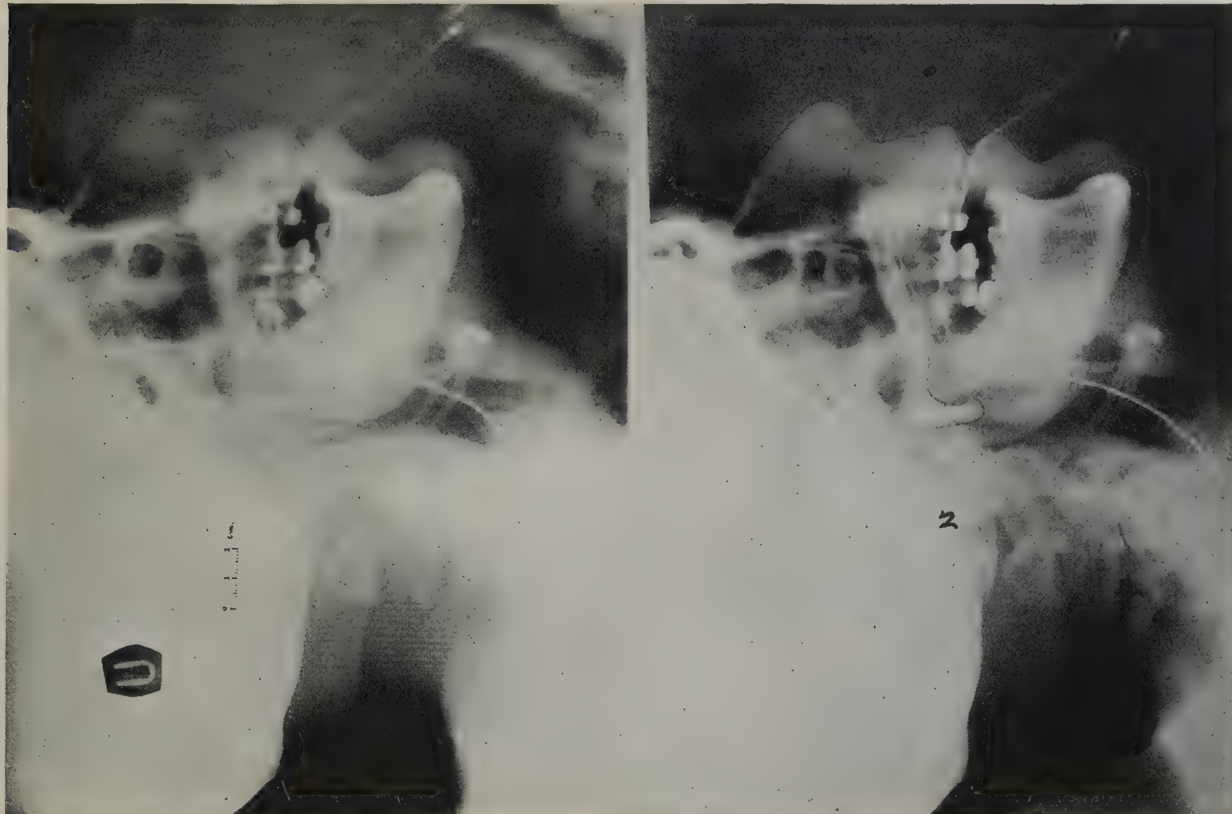


FIG. 239. Vowel *u* (oo) Same subject as Fig. 230. This vowel departs from the others quite radically. Again we note that the front tongue position is relatively unimportant, being here almost as closed as for *i* (ee) 230. Back pharynx resonator is decided.

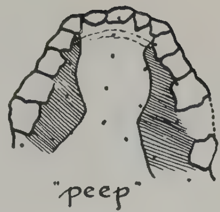


Fig. 240

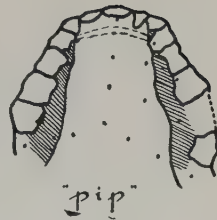


Fig. 241

Fig. 242

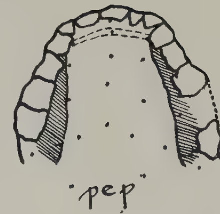


Fig. 243

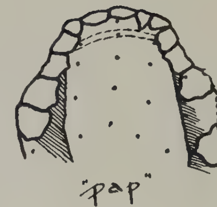


Fig. 244

Reduced just ½. So 1 mm. = 2 mm. or 1 sq. mm. = 4 sq. mm.

These palatograms pertain to the vowel series covered in the stereographic set of X-rays shown in Figs. 230 to 234, inclusive. But the palatogram shows the lateral or horizontal dimensions of a cavity whereas the X-ray photograph shows the perpendicular or median section. These two coupled with the front to back measurements of the cavity would make it possible for us to reconstruct that cavity just as it was, for we are then provided with the necessary computations in three dimensions. The author's laryngo-periskop makes it possible to obtain reliable lateral measurements for the back cavity as well. Applying the formulae on page 172 to these should make it possible for us to compute the characteristic cavity tones from data thus provided. And the equations of other scientists who advance air volume resonator cavity tone theories calling for formulae which might differ from those of Lord could be treated in the same manner. Padget's experiments showing the effect of varied coupling, would for example, eventually call for additional equations.

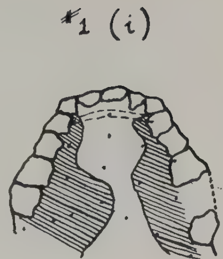


Fig. 245

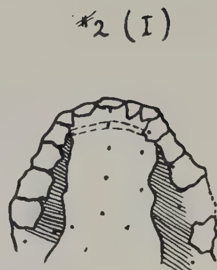


Fig. 246

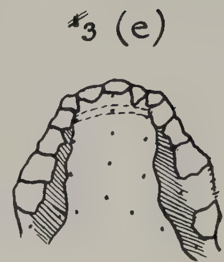


Fig. 247

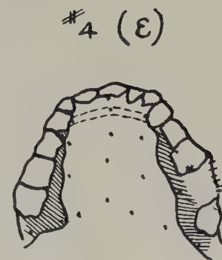


Fig. 248

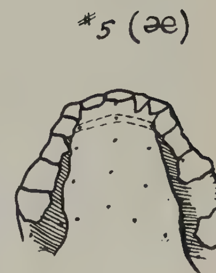
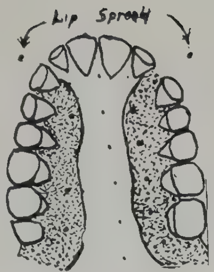


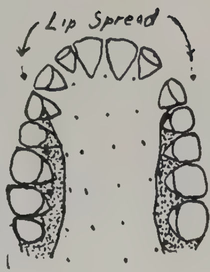
Fig. 249

Reduced just ½. So 1 mm. = 2 mm., and 1 sq. mm. = 4 sq. mm.

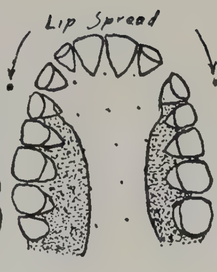
Prolonged Vowels by same subject as the one who pronounced for Figs. 240-244 and Figs. 230-239. Made at a different time and not incorporated in words as were Figs. 240-244. It is of interest to note that the same individual may use radically different tongue positions and cavities in order to produce exactly the same vowel. This is manifest in a comparison of Figs. 240 and 245.



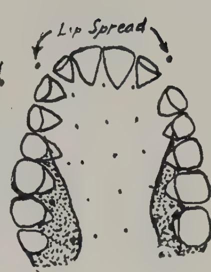
i (peep)
Fig. 250



$ɪ$ pip)
Fig. 251



e (fame)
Fig. 252



ϵ (pep)
Fig. 253

æ (pap)
Fig. 254

u (moo)
Fig. 255

Reduced just ½. So 1 mm. hereon = 2 mm., or 1 sq. mm. on the platogram = 4 sq. mm.

These palatograms showing the horizontal front mouth cavity measurements were made simultaneously with the X-rays on the lady subject 291, cuts of which are published in the author's Speech and Voice (Macmillan), and computations from which are given herein beginning on page 192 in Figs. 163 to 173, inclusive.

These experiments were used in the reconstruction of the cavities in clay shown herein on page 159; in order to ascertain whether the present air-volume resonator or formant theories would be supported. In the text we have noted that they were not and concluded that the surfaces were of more importance than they have been credited to be.

FIG. 256

Vowel æ (pap). Natural size. From our first set of X-ray experiments. At this time we were seeking objective evidence in favor of the Vowel Triangle. It was terribly disturbing to discover that the tongue ever took what appeared to be such an incongruous position for the production of an æ (pap). But no real scientist rejects the evidence merely because it fails to agree with his theory. So we set out to test the facts. That was 11 years ago, and now we feel justified in announcing, as we are doing herein, the results of our investigation. Since that time we have taken over 3,000 X-ray experiments on something over 400 subjects, old and young, English, French, German, Italian, and Spanish. And in order to perfect a technique have traveled back and forth several times spending long periods in almost every country in Europe wherever there was a laboratory or scientist who appeared to offer some detail that would serve that end. We have for several years now freely imparted that information to all who were interested and anticipate that there will shortly be a number who will in consequence be led to publish further X-ray experiments to throw more light on some of the numerous vexing problems treated herein.

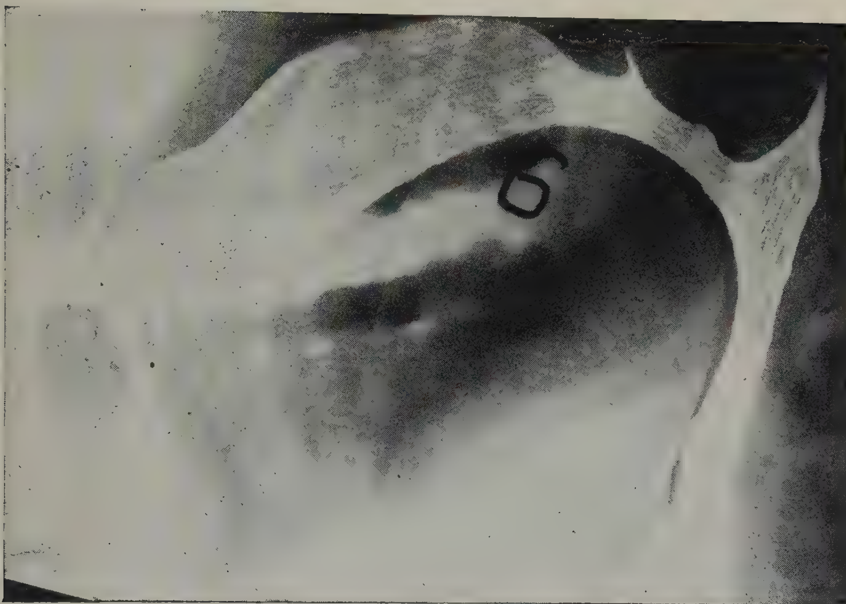


FIG. 257

Vowel ə (the). Natural size. Same West U. S. English male subject. Age. 40. Physician. Cultured but non-pedantic pronunciation. No marker used to delineate the median line or point of widest opening. Hence the experiment probably gives a distorted idea of the cavity size (for the reasons indicated in the chapters on technique herein). The throat cavity especially, probably appears to be very much smaller than it actually is. At this time our Velum median line delineation technique was also undeveloped, and since we were following the Scheier postulate that this line would be shown in that manifest in the greatest shadow, we get here the fantastic velum which causes us now to smile. Our process for obtaining the undistorted lip positions was also in embryo, hence they are here barely visible.

My first X-ray experiments sought to prove the Vowel Triangle

Fig. 270 *u* (tool)
Fig. 269 *U* (soot)
Fig. 268 *o* (tone)
Fig. 267 *A* (tall)
Fig. 266 ɔ (pot)
Fig. 265 ʌ (tut)
Fig. 264 ə (the)
Fig. 263 *a* (tart)
Fig. 262 *æ* (sat)
Fig. 261 ɛ (set)
Fig. 260 *e* (pate)
Fig. 259 ɪ (sit)
Fig. 258 *i* (peep)

(Continuation of description pertaining to Vowel Triangle cut on preceding page. See Figs. 258 to 270)

Figs. 258 to 270 show a series taken from my first X-ray experiments. At that time I was seeking evidence to prove the Vowel Triangle. So the experiments are arranged in that form.

The photographs show my own pronunciation and are the last made of myself since in the course thereof an X-ray burn began to show which caused me to lose my whiskers on one whole side of my face, and suffer considerable pain for a time. This resulted from too great eagerness to develop an adequate technique. That series developed however a final process for showing the median line of the Velum which it will be noted, shows clearly.

For this group we also succeeded in obtaining 17 exposures per second and have included under each Fig. the central frame (or rather the one of the moving pictures which shows the widest opening) in the transition from the consonant before the vowel to the one after it. This would undoubtedly show the most characteristic part of the vowel. It is unfortunate that all those consonants were not made point-lingual; for where such are used it is evident that the tip of the tongue very regularly barely departs from its point of contact. That manifestation alters the cavity and opening very decidedly.

This series is also of particular value because a conscious attempt was made to keep the lip position constant, so as to leave the tongue function as the only factor responsible for the creation of each vowel's quality. I thot at that time that the result would clearly demonstrate the tongue-arching vowel triangle shift.

It is needless to state that the *æ* (sat) position in Fig. 262 for example was terribly disturbing. We all had been thinking of the **a** (ah) series of vowels as calling for a flat in the mouth tongue position, and even Fig 263 for *ɑ* (tart) shows a center hump position I had always been taught to ascribe to *ə* (uh).

The manner in which the back cavity varied was more disconcerting still, as was also the failure of those X-rays to confirm the "open-closed" theory for *i* (peep) compared with *ɪ* (sit) or *e* (pate) compared with *ɛ* (set).

We have to add two further observations to the one we just made in regard to the tongue arching well back into the region of the *K* articulation for front as well as back vowels. **First,** that the front cavity fails to show the progressive widening diameter through:

i (peep), *ɪ* (pip), *e* (pape), ɛ (pep);

and this fact coupled with that above mentioned, which showed that the length of the cavity was essentially the same for the whole group of vowels combines to make the above summarized theories seriously questionable. But this is not the first time that observation has been made. Meyer's experiments conclusively proved that point some time ago. And Viëtor called attention to the fact. So since the perpendicular opening is not regularly progressive, it is very evident that the modification of the triangle scheme which makes the first vowels step down progressively along a perpendicular line instead of one which slants downward on a tangent from the alveolar ridge to the point for the low-mixed box on the tongue for an *a* (ah), fails also to portray the actual and essential facts. So the scheme now used by the International Phonetics Association, also lacks substantiation in fact even though it attempts to compromise with the facts by taking cognizance of the experimental evidence which showed indisputably that the front cavity was essentially the same length for all front vowels, and that the point of tongue arching for the whole group extended back to the juncture of the hard and soft palate. It is curious that compromises of that kind should ever be resorted to. The scheme as now used, fails in every way but one (viz.: that which has to do with variation in diameter) to represent the organ-pipe cavity tone theory which the old triangle represented; and it supplies no other in its place. A makeshift of that kind

cannot persist, and the only scientific procedure to follow would be to recognize the facts, and if a scheme must be had devise one that would represent them rather than compromise on partial changes in an exploded one. Hence the author considers more in detail in another chapter, usable schemes which might be substituted for the tongue-arching triangle which should be relegated to the scrap heap, and the sooner the better, since it has so little basis in fact.

As a second observation pertaining to tongue position in front vowels, we have to note the fact that the pharyngeal cavity, extending from the palate all the way down to the larynx, makes changes which are evidently quite as radical as any that were ever conceived of in the front buccal cavity. So any scheme such as that of the triangle, which seeks to trace vowel quality differences solely to modifications of the buccal cavity or upper mouth alone, or relegate the throat position to an insignificant role, would inevitably prove to be objectionable if for no other reason than this. The author would not be one to insist that that back cavity showed a regularly progressive decrease through the series of front vowels:

i (peep), *ɪ* (pip), *e* (pape), ɛ (pep), *æ* (pap).

But there is just as much regularity in that progression if not more than manifest in the front cavity. Yet he must admit that to him it would appear that the effect of the surfaces in altering the same, and the type of quality originally produced by the vocal cords, may yet prove to be quite as important as the influence of the cavity tone in creating differences in vowel quality. And until more conclusive evidence is available, one is hardly justified in going farther than a tentative acceptance of the idea involved in the old terms **tense,** and **lax** used to account for this failure of cavities to

show the progressive variations in size which we had expected. The author has elsewhere called attention to the fact that as walls become softer, the cavity tone actually becomes lower in pitch, and variations in tension must inevitably exercise a radical effect on the quality of tone produced.

Certainly it is true that an X-ray examination often shows a front cavity which is smaller for *e* (fame) than for *ɪ* (pip). And that even in the same subject. And a comparison of subjects immediately reveals the fact that this *e* (pape) may often be produced with a front cavity which is smaller than that of the *i* (peep). That discovery in the results obtained by the experiments of Meyer, struck Viëtor[1] very forcibly. Says he:

"Meyer has published a number of plastographic tongue outlines for front and 'mixed' vowels. . . which show our former views as to tongue articulation to have been for the most part erroneous.

". . . not less surprising is the discovery that the open *ɪ* should appear as a *mid-high vowel* whose *opening* for N. German *is* not only *greater than* for *e* but is almost *identical with* that of the ɛ. . . It is further disturbing to note the *tongue opening* for *S. German, Holland Dutch, and Italian ɪ is greater,*

[1] VIETOR, *Zur systematik der Vokalartikulation*, Miscellanea Phonetica, Association Phonétique Internationale to commemorate the 25th year of "Le Maître Phonétique" 1914. Italics and translation mine.

"Seitdem hat Meyer. . . eine grosse Anzahl nach seiner plastographischen Methode gewonnener Zungenkonturen der vorderen und der 'gemischten' Vokale. . . mitgeteilt, neben denen *unsere früheren Annahem über Zungenartikulation grossenteils als irrig erscheinen.*

". . . Nichts minder befemdlich ist die Feststellung dass das offene *I* . . . *als mittelhoher Vokal erscheint*, dessen *Abstand* im Nordd, nicht nur *grösser* als beim *e* ist, sondern sich mit dem des *ä* d. h. ɛ: nahezu deckt. Neue Uberraschungen bringt die Vergleichung der Zungenhöhen als identisch angesehener Vokale verschiedener Sprachen. So ist der Abstand der Zunge beim südd., holl. und it. *i sowohl durchschnittlich als* auch *an der engsten Stelle grösser,* und zum Teil beträchtlich grösser, *als* beim *nordd. e,* wahrend der des *südengl. Ii* oder *ij* den des schwed., frz. und it, *e* übertrifft. . .

". . . Ob die weitere exakte Forschung uns je ein gleich einfaches, ja überhaupt ein artikulatorisches 'Vokalsystem' im alten Sinne bescheren wird? Man darf es füglich bezweifeln."

not only on the average, but also at its narrowest point, and at times decidedly greater than for N. Ger. e; whereas that of the S. English ɪi or *ij is greater than that of the Swedish, French, and Italian e."*

So others had already noted the fact that ɪ (pip) is often more open than *e* (pape), and in a comparison of vowels produced by subjects of different languages discovered that the *e* (pape) might even appear as more closed than the *i* (peep). This disturbing manifestation need not be ascribed to the fact that the languages were different. For that would mean that the southern Englishman, or northern German would be constantly hearing *e* when the Italian used *i*. That is, if the Italian said *"si"* they would always hear *"se."* And we know that is not true. So we have to conclude that precise positions of the tongue in order to produce certain vowel qualities are not so important as we used to think. Little wonder that we failed to get results by following the vowel triangle theory and when a foreigner was saying *"pape"* we tried to make him say *"pip"* by insisting that he "close the vowel more!"

To conclude and summarize, we may note that so far as position of the vocal organs in the production of our vowel series is concerned, three, and possibly four, more or less interchangeable physiological processes seem to be utilized.

First, the "front" vowels

i (peep), ɪ (pip), *e* (pape), ɛ (pep), æ (pap),

all do show a decided tendency for the tongue to arch against the hard palate, but that this arching covers the full length of the same, and apparently never extends much beyond into the deadening folds of the velum and palatine-arch soft surfaces. And accompanying this tongue arching against the hard palate, is a distension of the back throat cavity in such a

manner as to eliminate the damping influence of those back soft surfaces as much as possible. But it does not appear that we can postulate any universally regular progression from one of these vowels to the other, in either the amount of arching against the hard palate in the front, or the decrease of the throat cavity in the back.

Second. The *A* series of vowels, passing from the above

æ (pap) to *a* (ah), *ɔ* (aw), and sometimes *o* (oh) (where the latter makes good use of the lips) regularly shows a constriction between the tongue and the pharynx, down in the neighborhood of the epiglottis. This seems to be the controlling factor in the production of these vowels, and produces for them a typically flaring megaphone-like front horn, which increases their natural loudness. But this horn may be eliminated by making the front part of the tongue take a position for *i* (ee) or almost any other vowel, without such detriment to their characteristic quality that we no longer recognize them. It would appear therefore, that nature's main purpose in the creation of this lower constricted epiglottal-tongue opening is for the purpose, possibly, of preventing the creation of any back pharyngeal resonator. So here, just as the front series arch against the palate, these may be said to arch against the lower throat, or pharyngeal wall. This discovery substantiates a vowel triangle which antedates our modern scheme, since it placed the *a* at that point, using the side instead of the bottom angle, placing the *u* at the latter and *i* at the top. This we consider in Chapter 13. See Fig. 298.

Third, the "labialized" vowels, of which the *u* (fool) is to be considered the most characteristic, vary the closure of the lips. Like the *a* (ah) this *u* (oo) may

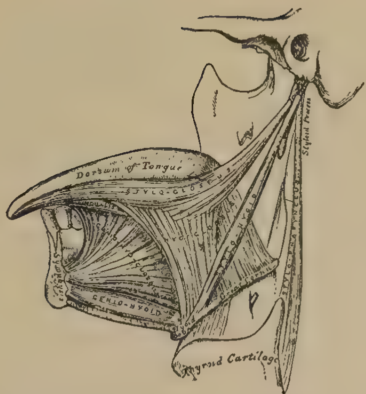


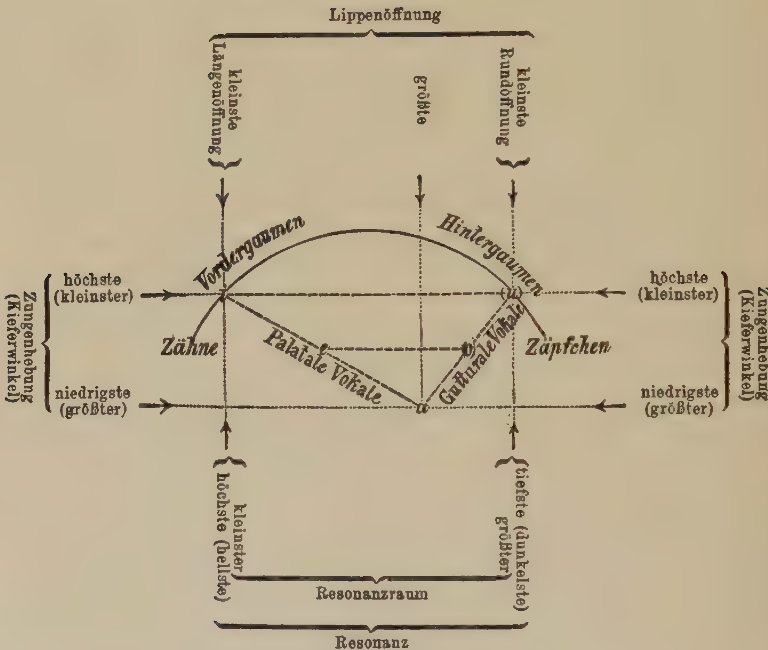
FIG. 271. (From Gray's Anatomy.) The most important interior muscles (eliminating those of the palatine arches and the lips) involved in vowel cavity alterations. Note the intimate relation between the Hyoid and Thryoid, and the possible function of the genio-hyoid in back cavity alteration of vowel quality.

take all kinds of front tongue positions and still retain its identity. And all vowels which utilize a lip rounding seem to be able to successfully simulate the same quality by substitution of other vocal organ function. Variation in the pharyngeal resonator seems to be the one most commonly utilized for that purpose. Where its pitch has to be made as low and barrel-like in quality as possible, and the accompanying deadening influence, exercised in order to create the vowel quality necessary, the arching is likely to be up against the soft palate with a very narrow opening. But the observer must remember that this position is only one factor; it must be accompanied by an extreme lowering of the larynx, and at times by a radical pulling forward of the base of the tongue, and hyoid bone, so as to distend the lower part of the cavity as much as possible. This seems to be what is done in the production of a German umlaut *ü*, or the French *y* (tu) where the lips are not used, and some kind of substitution is resorted to. And at times it is also decidedly noticeable in the production of an unrounded *u* (Sue). So in general, it would appear justifiable to conclude that lip rounding and involvement of a more or less low-pitched decidedly actuated pharyngeal resonator may be made to alternate in function.

Fourth. The ə (th*e*, ide*a*) series of vowels offers more difficulty.

ə (the, *a*, d*oe*s, ide*a*) ; *U* (foot) ʌ (cut, ton, s*o*me). They may be closely allied to almost any of the others. They most commonly manifest a cavity which is wide open from the vocal cords to the lips. So they may be much like the *æ* (at), or ɛ (bet, *I* (bit). But they also greatly resemble the vowels *a* (ah), ɔ (aw), *o* (oh), having as a rule but a somewhat slighter constriction of the epiglottal opening. And if the lips

close on a vowel in the ə (uh) tongue position it is readily turned into an *o* (oh) or *u* (oo). So that the *i* (see) is about the only vowel in our group which is clearly segregated. And we have noted elsewhere, the fact that almost any unaccented, unstressed, muffled, or other vowel produced with very decided squeezing (shortened quantity) or on suddenly and excessively lowered pitch, is likely to be heard as an ə (*uh*). Hence all of our English unaccented vowels are tending to be leveled to this one, excepting *i* (see) and the above mentioned fact may account for it alone passing to ɪ (it).



Schema der einfachen Vokale.

FIG. 272

Viëtor's Vowel Triangle

(with accompanying physiological explanations) which in his last article he acknowledged to be overthrown by the facts shown in X-ray and plastographic analyses. This now so commonly used scheme is the tongue-arching triangle we have herein designated as fallacious. In the text the reasons have been given, and Chapter 13 traces some of the older side *a* (ah) and other classification arrangements for the vowels, many of which could with advantage be substituted for this one. See his Elemente der Phon. Reisland, 6th ed. p. 31).

CHAPTER XIII

AN ACOUSTIC SIDE *a* (ah) TRIANGLE JUSTIFIABLE. USABLE CLASSIFICATION SCHEMES

"Brücke, and after him Hoffray, maintains that the speech physiologist like the zoologist and botanist, should classify only the characteristic types (of speech sounds); the innumerable varieties which naturally find no place in this system, then automatically group themselves around these. . .

"Most vowel systems. . . take each vowel as a unit and then order the vowels in rows, which are often not even named, or carry inadequate names, such as lip-series, tongue-series, lip-tongue-series, respectively for *u—o—ɔ*, *i—e—ɛ*, *y—ф—œ*.

"When one for that reason finally decides to renounce the customary system of ordering (speech sounds), that by no manner means that he gives up every type of systematic ordering, or that he undervalues the struggle towards a systematic phonetics. On the contrary it means only that he transfers his systematization to another orientation. . ."

—Jespersen[1] (1904)

Since X-ray examination of the exact tongue position taken in vowel articulation has shown both the scheme and theory represented in the tongue-arching vowel triangle to be fallacious; and has also indicated the Bell-Sweet system to be quite as defective, we are

[1] JESPERSEN, O. (cf. his *Articulations of Speech Sounds*). The above is taken from his *Phonetische Grundfragen*, (1904) Teubner, Leipzig, which was translated in part from the Danish. Material in parentheses and translation mine. First paragraph from his p. 104; second, p. 107; third, 108.

	primary (narrow) Krapp		
	back	*mixed*	*front*
high	1. *hbn* gälisch **laogh** B. Sw.	7. *hxn* ə amer. **her**, **sir** B.; welsch **un** Sw.[1]; [russ. **syn** St.] [1] schwed. **upp** (1874).	13. *hfn* i engl. **feel**, frz. **fille** B.; franz. **si** Sw.[1]; [d. **ihn**, **sie** St.] [1] schott. **u**, geleg. engl. **feel** (1874).
mid	2. *mbn* ʌ engl. **up**, **turn** B.; engl. **but** Sw.[1]; gel. engl. Sw. 1902. [1] geleg. engl. **but** (1874).	8. *mxn* əː ir **genuine**, **reply** usw.; frz. **de**, **le**, frz. **un** B.[1]; d. **Gabe**, am. 1. Elem. in **earth** Sw.[2]; [dän. norw. **Gave**, schwed. **gosse** St.] [1] + d. **Zeit**. [2] **earth** fehlt 1874 usw.	14. *mfn* e engl. 1. Elem. in **day**, schott. **day**, frz. **est**, B.[1]; [d. **See** St.] sch. **say**, frz. **été** Sw.[2]; d. **See** Sw. 1902. [1] frz. **et**. [2] dän. **steen** (1874).
low	3. *lbn* schott. **up** B.[1]; Cockney **park** Sw.[2] [1] + schott. **out**. [2] gel. schott. **but** (1874).	9. *lxn* Somers. **sir**, Cockney **penny** B.; engl. **sir** Sw.	15. *lfn* ɛː engl. **let**, frz. **bête**, frz. **vin** B.; [schwed. **lära** St.] Sw.[1]; engl. **air** Sw. 1902. [1] sch. u. gel. e. **men** (1874); engl. **air** (1879); **care** (1886).
			round
high	4. *hbnr* u engl. **ooze**, **pool**, d. **Buch**; frz. **toujours** B.; frz. **sou**, sch. **book** Sw.[1]; [d. **du**, it. span. **tu** St.] [1] sch. u. gel. e. **fool** (1874).	10. *hxnr* nordir. **too**, **look** B.[1]; [norw. **hus** St.] Sw.[2]; schwed. **hus** Sw. 1902. [1] schwed. **u**. [2] schwed. **hus** (1874).	16. *hfnr* y d. **über**, **Glück** B.; frz. **lune** Sw.[1] [1] d. **übel**, dän. **Lys** (1874).
mid	5. *mbnr* o schott. **go**, am. **ore**, engl. 1. El. in **go** B.; d. **so** Sw.; [frz. **seau**, it. **dolore** St.]	11. *mxnr* ɔ Yorksh. **come**, ir. **Dublin**, frz. **homme**, **on** B.; — Sw. closed Ripman	17. *mfnr* ø frz. **dû**, ~~**but**~~, schott. **gude** B.; frz. **peu** Sw.[1]; [d. **schön**, **Töne** St.] y= Rip ø= [1] dän. **föle**, d. **schön** (1874).
low	6. *lbnr* ɔː A engl. **all**, **law**, geleg. **wash** B.; engl. **law** Sw. Jones Krapp	12. *lxnr* ir. **her**, **sir**, 1. Elem. in ir. **I**, **my**, frz. **an**, **en** B.; — Sw.; schwed. **upp** Sw. 1902.	18. *lfnr* ø frz. **peur**, ~~**jeune**, d.~~ Rip **schöne**, **Stöcke** B.; [schwed. **för** St.] Sw[1]; frz. **peur** Sw. 1902. [1] dän. **störst**, gel. d. **Götter** (1974); frz. **peur** (1877).

B = Bell Sw. = Sweet St. = Storm

	wide		
back	*mixed*	*front*	
19. *hbw* Cockney *up*, *turn*, engl. -*tion*, -*tious*, -*geous*, -*our* usw. B.; — Sw.[1] [1] gel. engl. **but**, engl. **eye** (1874).	25. *hxw* engl. **return**, **limit**, **captain**, **there is**, **the man**, **places** (Plur.), **pretty** B.; engl. **pretty** Sw.[1]; — Sw. 1902. [1] — (1874); gel. engl. **pretty** (1877).	31. *hfw* engl. amer. **ill** B.[1]; engl. **bit**, 1. El. in **see** Sw.[2]; [engl. **pity**, nordd. **Fisch** St.]; engl. **pity**, **fear** Sw. 1902. [1] + am. **new**. [2] + engl. **fear** (1886).	*high*
20. *mbw* engl. **pass**, **task**, **path**, **pathetic** B.; **father** Sw.; [it. **padre**, nordd. **Vater** St.]	26. *mxw* engl. **alderman**, **Greenland**, **-ance**, **-al**, **ant**, **-able**, **a** (Art.), oft auch **-er**, **-yr** B.[1]; **eye**, **better** Sw.[2] [1] + Cockn. **day**. [2] **eye** fehlt 1874; **-er** fehlt 1877.	32. *mfw* engl. **care**, **-ment**, **-ness**, schott. **ill** B.; [engl. **men** St.], engl. 1. Elem. in **say**, Sw.; [**Männer**, **Ähre** St.]; engl. **men** Sw. 1902[1]. [1] gel. engl. **men**. dän. **læse** (1874); dän. **træ** (1877).	*mid*
21. *lbw* engl. **arm**, **alms**, **father**, sch. **man** B.[1]; schwed. **mat** Sw.[2]; [südd. **Vater** St.; südostd. **Vater** Sv.] [1] d. **Kaiser**, **Haus**. [2] schw. **fara**, sch. **man** (1874); schott. **father** (1877).	27. *lxw* engl. **-er**, **-ir**, **-yr**, **err**, **perform** B.[1]; **how**, port. **cama** Sw.[2] Ripman [1] + Cockn. **up**. [2] gel. schott. **err** (1874).	33. *lfw* engl. **hat**, ir. **half**, frz. **vin** B.[1]; engl. **man** Sw. [1] + schott. *eye*, Cockn. **now**, **our**.	*low*
(gerundet)			
22. *hbwr* engl. **foot**, **put**, **poor** B.; engl. **put**, 1. El. in **too** Sw.; [d. **Mutter** St.]	28 *hxwr* engl. (colloqu.) **awful**, **nature**, **fortune** B.[1]; engl. **value** Sw.[2]; [norw. **huska** St.]; — Sw. 1902. [1] + am. **do**. [2] — (1874); schwed. **upp** (1877).	34. *hfwr* frz. **une**, **du** B.[1]; — Sw.[2]; [dän. **Lyst** St.] [1] schott. **boot** (noun). [2] dän. **synd** (1874); d. **schützen** (1877).	*high*
23. *mbwr* engl. **oar**, **pour**, **door**, **sore** B.[1]; 1. El. in **boy**, **no**, d. **Stock** Sw.[2] Krapp [1] + frz. **chaud**. [2] gel. sch. **no** (1874).	29. *mxwr* geleg. engl. **eloquence**, am. **whole** B.; e. 1. El. in **follow**, frz. **homme** Sw.[1]; [norw. schw. dial. **godt** St.]; — Sw. 1902. Krapp Ripman [1] — (1874).	35. *mfwr* indiv. frz. d. B.[1]; frz. **peur** Sw.[2]; [**Völker**, frz. **peuple** St.; niederd. **sön** = Sohn? Sv.]; — Sw. 1902. [1] frz. **jeu**, sch. **boot**. [2] dän. **en dør** (1874); nordd. **schön** (1877).	*mid*
24. *lbwr* engl. **on**, **off**, **or**, **boy**, gew. **wash** B.; engl. **not** Sw.	30. *lxwr* engl. (colloqu.) **occasion**, **consist**, ir. **not**, Cockney **ask**, amer. **Chicago** B.; — Sw. Krapp	36. *lfwr* Cockney *out*, **now** B.[1]; — Sw.; mit *outer* Rundung d. Götter Sw. 1902 Ripman [1] + schott. *I'll*.	*low*

Symbols according to Jones, Krapp, Ripman

naturally forced to seek some more accurate scheme to serve in our attempts to order vowels systematically. For an accurate device is quite as valuable in speech work as in Botany, Zoology or Chemistry.

A careful examination of the X-rays taken on a large number of individuals would seem to indicate an interplay of at least three different factors causing an alteration in cavity function. These are probably largely responsible for the general tendency on the part of scholars, to force the classification of vowels according to a triangular scheme. A purely imaginary and subjective analysis of their own pronunciation, has led many to such an arrangement. We trace that tendency back at least 200 years. Yet none of them had any really reliable information on which to base part of their conclusions. For it was only with the advent of the X-ray and other modern equipment, that a careful examination of cavity position was made possible. We can consider those historical schemes and their application to the facts now made clear, in another chapter. But we had best pause here long enough to note those facts which the X-ray examination has shown in regard to cavity position.

Most of the earliest triangular schemes seem to have been arranged to represent primarily, the opening and closing of the jaws and lips during the production of the vowels. After all, everybody could see what was happening to the outside of the mouth as the various sounds were pronounced. So it was perfectly natural that the first of the physiological classification systems should have turned towards a representation of this visible exterior manifestation. It seems to have been noted at an early date, that the jaws and lips were normally open widest during the production of *a* (ah). It also appeared that the jaw or teeth opening got nar-

rower as one passed to *e* (bay), and still narrower for the production of *i* (fief) ; or in passing from the *a* (ah) through what we call the back series, that the lips began to pull in the corners and narrow their opening for *o* (oh), narrowing still more for *u* (oo). Hence the *a* (ah) was placed indiscriminately at the top, side, or bottom, merely to represent a departure norm, and the *i* (ee) and *u* (oo) at the extremities of either leg to represent the maximum closure as one moved away from the norm in either direction.

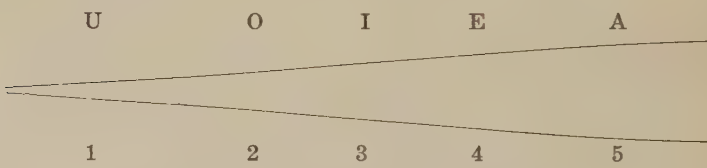
Such were those of Hellwag, Fig. 273, and Du Bois-Reymond, Fig. 277, which were among the earliest. But much the same scheme, though somewhat more elaborated, is shown in Fig. 279. And in all of these, the idea of opening and closing in the jaw and lip aperture was the one which was primarily involved in the schematic representation classifying the vowels along a triangle.

Of course it is true that at least as early as 1791, there were those who used two triangles, one below the other to represent not only the opening in the facial aperture, but also one postulating a corresponding progressively varying cavity size. This was the arrangement shown in Fig. 288 used by Wolfgang v. Kempelen. It will be remembered that his scheme grew out of attempts to construct a machine that would artificially reproduce speech.

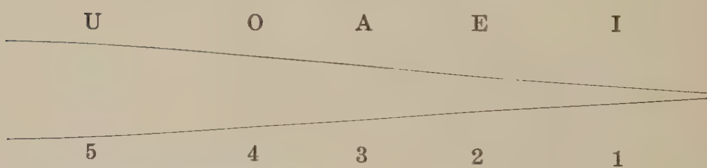
The Abbé Mical, in France, Kratzenstein in Russia, and Kempelen [1] in Austria, were all engaged about this time in attempts to reproduce vowels artificially; and in the end all three seem to have obtained about as good results as we have ever been able to accomplish since (to judge by what we can get out of a reproduction of

[1] KEMPELEN, Wolfang V. *Mechanismus der menschlichen Sprache.* Wein (1791). See above Chapter I, page 4.

their apparatus). Kempelen traveled to France with his machine and a fake mechanical Chess Player; but he apparently failed of a hearing before the French Academy of Sciences; however, he published a book dealing with his studies of speech in 1791. In this work he protested the assumption that the opening and closing of the jaw could be considered the scientific cause of all differences in vowel quality. And therein he called specific attention to the effect the size of the tongue channel might have. He arranged the five basic Latin or so-called primary vowels; *a* (ah), *e* (bay), *i* (ee), *o* (oh), *u* (oo) along two triangles designed to show the degree of opening, ranged from 1, as the narrowest, to 5 as the widest, as follows:[1]



Opening of the Mouth (lips-jaws)



Opening of the Tongue Channel

A couple of decades later Willis in England used this idea as a basis for about the first really scientific experiments we have record of, seeking an explanation of what causes difference in vowel quality. He it was

[1] id. Table X, p. 194.

who drew the conclusion and postulated the vowel pitch law involved in the cavity tone theories, to-wit:[1]

(a) **The larger he cavity, the lower the pitch,**
(b) **The larger the aperture the higher the pitch.**

Meanwhile triangular schemes continued to be used with the old implications both before, and at least as early as 1780 with Hellwag,[2] and after, down to at least as late as 1884 with Trautmann.[3] But there can

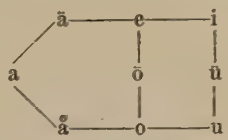


FIG. 273

Hellwag's First Vowel Triangle (1780)

It remains a more reliable scheme than the present tongue-arching one with the *a* (ah) at the bottom to represent the supposed cause of vowel quality as due to variation in the tongue position of the front mouth. But the present investigation would indicate that the back throat, epiglottis, cavity wall hardness or softness, and vocal cord function, are in all probability of even greater importance.

surely be no doubt but what those schemes came to be rather highly conventionalized, and were often used by authors merely as a convenient mnemonic device, mainly for the purpose of ordering the vowels in accordance with the quality they heard. The actual physiological theory which resulted in the creation of those schemes may have been the thing farthest from the author's mind. Certainly this must be true of Miller's use of the same pyramidal arrangement of a vowel series in which he places the *a* (ah) at the top.

[1] WILLIS, *On Vowel Sounds, and on Reed-organ Pipes.* Trans. Camb. Phil. Soc. (1830) III, 231. Translated into German in Ann. d. Phys. u. Chem. 1832, XXIV, 397.

[2] HELLWAG, C. F. Ms. *Entstehung d. Buchstaben* a. d. Ubereinstimmung i Lauts (1780).

[3] TRAUTMANN, *Sprachlaute* (1884) p. 43.

And both Fletcher[1] and Crandall[2] have informed the author personally that this was true in their cases where the *a* (ah) is placed at the bottom. Besides that is very evidently the case in the usage which Ellis and Helmholtz[3] make of the triangle as employed by du Bois-Reymond.[4]

Most of the earlier schemes were devised to fit either the French or German. And both of these languages

u ü i

o ö e

å ä

a

FIG. 274

Hellwag's Second Vowel Triangle (1781)

The fact that the *a* (ah) is turned to the bottom probably has no significance. His theory was no doubt essentially the same as in the first, and quite unlike the theories we now read into the triangle scheme. The fact that the *u* and the *i* fail to continue the triangle projection seems to justify that assertion.

have the rounded front or so-called lip-tongue vowel series of which Jespersen speaks. In German they are called "umlaut" vowels since they are usually represented with two dots over the vowel letter as in "schön" and "tür." So it came about that most of those schemes provided three rows of vowels leading off from the *a* (ah) ; one for what we now call the front series, one for the back, and another in the middle for the umlaut group. Then very often line runners were used leading from vowel to vowel in order to indicate that by combining the quality of one with another, the inter-

[1] FLETCHER, Harvey. *The Nature of Speech and Its Interpretation* (1922) Jour. Franklin Institute, Vol. 193, No. 6, p. 731.

[2] CRANDALL, I. B. *The Sounds of Speech,* (1925) Bell Technical Jour. Jour. Vol. 4, No. 4, p. 603.

[3] ELLIS translation and annotation of HELMHOLTZ, *Sensations of Tone.* 4 ed. Longmans Green Co., N. Y. (1912), p. 105.

[4] du Bois-Reymond, F. H. *Cadmus* (1862), p. 152.

mediate vowel resulted. Such was that first scheme of Hellwag's (1780) above referred to.

The fact that he turns the *a* (ah) to the bottom[1] in his 1781 and 1783 writings would not seem to have any significance, or bearing on our modern scheme since it probably had no reference to the modern theory of variation in the resonance chamber by progressive shifts downward and backward (or forward) of the tongue position. These he ranges thus:

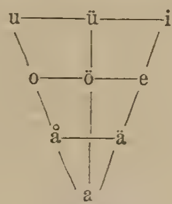


FIG. 275

Hellwag's Later Vowel Triangle (1783)

The location of the umlaut vowels in between show that the conception he is trying to represent was a purely schematic one indicating vowel to vowel transition in acoustic terms rather than the alveolar-velum tongue-arching one we have all been of late years trying so hard to get along with. Practically any acoustic scheme would be found more reliable than our present tongue-arching Vowel Triangle.

Chladni[2] (1809) placed his *a* (ah) at the top just as Miller[3] recently did. And if we may judge by the sym-

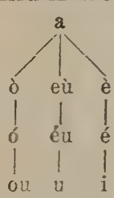


FIG. 276

[1] HELLWAG, C. F. *Dissertation inauguralis physiologico-medica de formatione loquelae.* Tübingen (1781), and his Ms. "zum eigenen Gebrauch" (1783).

[2] CHLADNI, *Traité d'acoustique.* Paris (1809), p. 70.

[3] op. cit.

bols used, Wheatstone[1] was much influenced by the general idea of the first.

So far as Wheatstone is concerned, an examination of his rather short article republished in Capter II herein, makes it clear that he had in view the physics rather than the physiology involved. Chlandi probably also had in mind the acoustics or what he heard as characteristic of the vowels.

Du Bois-Reymond[2] (1812), however, used his to give a graphic representation of the mouth cavity, or jaw position, the type of scheme we spoke of at the beginning of this chapter. So like the preceding one given above, it would make little difference which way the vowel *a* (ah) were turned, though he placed it at the side:

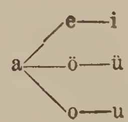


FIG. 277

These latter two seem to be the ones which were so largely used by physiologists and physicists in the years following their appearance. And generally they are credited to one of those two authors, so it is evident that they were the ones who influenced their spread. And well they might where only the five primary vowels and the two intermediate umlauts are considered. For these vowels fit a triangle scheme nicely.

Brücke as late as 1856 turns the *a* (ah) towards the top again, and adds more vowels so as to make the scheme somewhat more complex, but makes his a regular triangle with completely sloping sides like the

[1] WHEATSTONE, Chas. Westminster Review (1837) Vol. 28, p. 30.
[2] Du BOIS-REYMOND, F. H. *Musen* (1812).

second Hellwag scheme given above were it was turned upside down.

a

a^e a^o

e^a a^{oe} o^a

e e^o o^e o

i i^u u^i u

FIG. 278

Brücke's Vowel Pyramid (1856)

Still primarily an acoustic scheme as was usual before our pernicious tongue-arching idea was injected. Compare this arrangement with that of D. C. Miller and other careful modern scientists, where the acoustic facts are made the basis for classification.

i

e

ü

E

a Ö ö

O

y

o

u

FIG. 279

Techmer's Vowel Triangle (1880)

Still by far the most sensible arrangement for those who insist on the usage of a triangle.

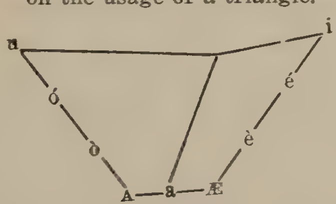


FIG. 280

Techmer's Triangle (1865) as Viëtor would have had it.

From that time on, vowel literature begins to be loaded with a plethora of classifications, diagrams, and alphabets. Philologists and other linguists take an

	Back		Mixed		Front	
		Nasal		Round		Round
	Nasal	Round			Nasal	Nasal
Close		E. pool			E. feet	F. pu
		E. put			E. pit	G. dünn
Half-closed		E. pole			E. fate	F. peu
Half-open		G. Sonne	E. villa	F. le	E. pet	G. können
		F. homme F. pont	E. burn		E. fairy F. pin	F. peur F. un
	E. but				E. pat	
Open	E. father		F. patte			
	F. pâte F. pan	E. Paul				
		E. pot				

FIG. 281
Laura Soames adaptation of the Bell Sweet Box Schemes (1891)

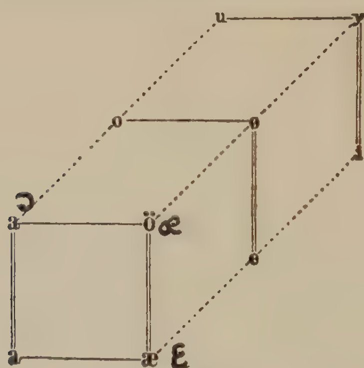


FIG. 282
Forchhammer's Clever Acoustic Scheme

... = jaw movement ═ = lip —— = tongue

I have written in the three symbols as used herein in order that it might be better understood. It will be noted that the ready transition we may make from certain vowels to others is provided for. The three basic types serving as points of demarcation are indicated for the *a* (th) *i* (ee) *u* (oo); and by postulating another dotted line for the lower left side corner of the box, provision could be made for a fourth basic type in the ə (uh) series, departing again from the *a* (ah) corner. ═ indicate involvement of the lips. —— show that of the tongue. .... for the jaws. This latter could drop out in favor of the straight line —— since the causal vowel factors involved in movements of the jaw are essentially the same as those of the tongue.

especially active part. Now appear squares divided off into smaller compartments like the Bell-Sweet system dealt with in detail in our chapter on Tongue-position; other boxes varying however radically from this one; crosses of several types; circles; and diagrams

i é è a ò ó u
ö̀
ö́
u

FIG. 283
Trautmann's Acoustic Scheme (1877)

ü
ö́
ö̀
u ọ́ ò aȧ è é i
ö̀
ö́
u̇

FIG. 284
Trautmann's Later Acoustic Scheme (1884)

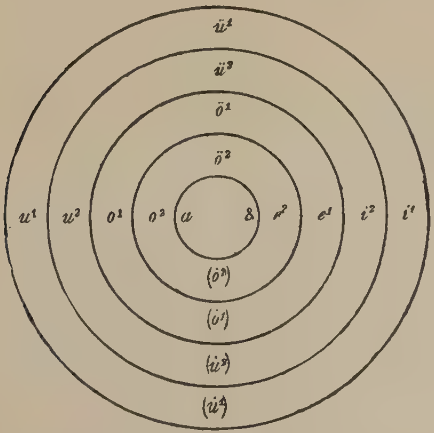


FIG. 285
Winteler Sievers Scheme (1876)

so complex that we can hardly describe them. And with the appearance of Bell's "Visible Speech" in 1867, the tendency towards seeking a physiological orientation for classification system, gets stronger and stronger. This is particularly true among philologists and language teachers of later years who knew the

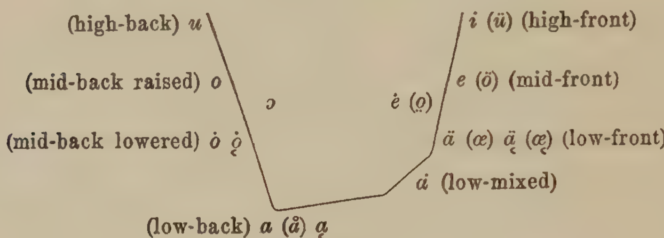


FIG. 286
Paul Passy's Tongue-arching Scheme of 1888

This is the language teacher's period when Passy's genius lends impetus to the usage of phonetic instruction in the teaching of foreign idioms. This scheme more nearly approximates the present one used by the International Phonetic Association, and cannot in reality be called a Triangle at all. It is esentially schematic in an imaginary tongue-arching sense, and stands almost isolated with little or no basis on principles of physics, or known acoustic law. So since its tongue-arching implications are proved to be unimportant as factors causing vowel quality differences; and since the physiological appears to be an unreliable basis of classification, there would appear to be wisdom in discarding such schemes and physiological terminology in general, in favor of some other based on known acoustic and other facts. Recommendations to that end follow at the close of this chapter.

least about the physiology and physics of the vowel. And all kinds of smattering physical laws, and wild assumptions such as those of Sweet, heretofore referred to, begin to take their places in those schemes as a part of a theory used to account for vowel quality differences. With the coming of the language teaching reform movement, and the turning of greater and greater attention to the teaching of pronunciation, it

was inevitable that a mass of language teachers with practically no preparation in the scientific subjects involved in the vowel problem, should begin to grasp wild-

	Vélaires.		*Mixtes.*		*Palatales.*	
(*fermées*)	u	ɯ	ü	ï	y	i
(*mi-fermées*)	o	ʌ	ö	ë	ø	e
(*mi-ouvertes*)	ɔ	ʌ	ä	œ	ɛ	
(*ouvertes*)			α	a		

FIG. 287
Paul Passy's Triangle of 1890
A compromise between the older acoustic and the then developing tongue-arching ideas for such schemes.

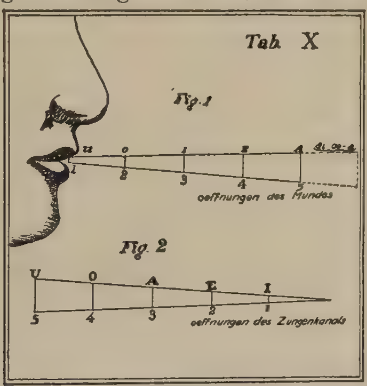


FIG. 288
Kempelen's Vowel Scheme (1791)
One of the earliest graphic representations. It will be noticed that one triangle shows the progressive opening of the jaws and the other that of the cavity. Willis later made this scheme the basis for what appears to be the first scientific investigations into the physical cause of vowel quality differences.

ly at some scheme that would serve them. And since we knew so little about the actual physiological cause of vowel quality differences, and theories were so conflict-

ing, nobody could effectually oppose any scheme they took over. That was the situation when the tongue-arching vowel triangle was pushed forward. Its pseudo-scientific theories would be bound to impress such a group. And among many philologists especially in the Romance group, it came to substitute for the earlier, and as we now know more justifiable, acoustic and lip-tongue-pharynx triangles which had been in

	Back	Mixed	Front	
High	food foot		eve ill	High
Mid	old art	ever up	ale men	Mid
Low	orb not	turn	care man	Low

FIG. 289

P. W. Carhart's Triangle (1910) in the New International Dictionary

It shows the modern Bell-Sweet tongue-arching idea underlying the scheme. Note that his mixed vowels made of those in the ə (uh) series, now occupy the position formerly held by the umlauts as in Passy's Fig. 256. Compare Fig. 250.

vogue among certain of their predecessors. Then it was forced to serve as an explanation of certain linguistic changes, such as those involved in the so-called raising of certain vowels; whereas the inconsistency which became manifest when the same law was applied to other vowels, identical combinations, and like situations was variously glossed over and otherwise lamely explained away.

The philologist should have some scheme which would indicate those various historical vowel changes

which are known to have taken place. And such a triangle as that used by du Bois-Reymond served quite well for German, and even English and French, or other languages. It showed how an *a* (oh) might pass to an *e* (bay) through the intermediate umlaut *ö* (schön). But where it came to postulate an umlaut vowel to account for similar transitions in a language such as Spanish, where there is no conclusive evidence that such ever existed, merely in order to force the application of the scheme, there can surely be no doubt but what it becomes pernicious. And the same thing may be said of the so-called "indefinite" vowel *ə* (uh), whose existence as a vowel entity in the Spanish of the present or the past we have not as yet proved.

Yet in spite of all he has said, the author sees no objection to the use of a triangle right now, where it is possible to make it conform to the known facts. This is possible if we cease making a too literal application of the minutely progressive opening idea, and return preferably to one of the triangles in which the *a* (ah) was placed at the side or at the top.

aȧ
ò ö̀ ȯ̀ è
ó ö́ ȯ́ é
u ü u̇ i

Fig. 290
Trautmann's Pyramid (1884)
An arrangement based on the jaw separation. It will be remembered that this was perhaps the first idea involved in triangle schemes.

As already indicated these were sometimes also in part physiological, since they were used to designate the progressive jaw or lip, and also at times tongue-canal opening, as one passed in either direction from the vowel *a* (ah) as a norm. It is still so used by some

scholars. And while it cannot be considered all sufficient, yet since it provides for a representation of a possible interplay of at least three variable physiological conditioning factors, one of which is the lips, the author would rather favor its use where the scholar demands a triangle for his scheme.

Right here, however, he desires to make it clear that, first, he has no classification scheme to urge, and second, feels very strongly after his X-ray investigations herein reported, that all schemes which are based on a physiological orientation are bound to be seriously defective. He is of course not the first one who has raised his voice to make that cry; for Rousselot, Trautmann, Sievers, Evans, and a host of others have done so. He is therefore under no illusion that his voice will be heard. And for that reason he makes this concession, recommending a return to the older side *a* (ah) acoustic triangle, for those who must use one.

The only facts which we know, and which we can rely upon, are those which involve the vowel as we hear it. We are still a long way from having satisfactorily decided exactly what the physiological cause of that quality difference is. And until we have definitely and unmistakably fixed that cause, the author cannot see how we can portray it on any scheme. Of course it is also true that we have not as yet been able to get uniform results in our computation of the characteristic pitches manifest in the various vowels. For each investigator who tackles the harmonic analysis without being influenced in any way by the work of others who preceded him, gets different results. If the theories the author has developed in his Speech and Voice (Macmillan) in regard to surfaces and their effect upon vowel and voice quality through damping or accentuating the upper partials, and that which

pertains to the manner in which the vocal cords modify quality in the original sound emitted, are finally justified, they may go far to explain those discrepancies.

	Front.	*Mixed.*	*Back.*
Closed	iː, i		uː, u
Half-closed	e		o
Half-open	ɛ	əː, ə	ʌ
Open	æ, a	ɑ	ɔː, ɔ

FIG. 291
The Real Tongue-arching Vowel Triangle

The scheme the International Phonetic Association made the *vade mecum* of language teachers. There can now be no question but what X-ray analyses prove this theory to be fallacious. And their more recent triangle which dropped the front series line straight down, is a poor compromise with the facts. Since it breaks into the basic theories of physics which the original represented, this new form merely makes the tongue-arching scheme more objectionable; for it now stands isolated as a make-shift arrangement. The I. P. A. will hardly drift permanently into that same attitude of dogged clinging to worn out antiquated symbols which was responsible for our present hopeless English spelling; for it was this latter which was largely responsible for the creation of the Association. In due time, therefore, we may expect a substitution of some better classification scheme. The sooner the old physiological basis is discarded the better off we will be; and no doubt the Association itself will be the one to lead the way out of present unfortunate confusion and inaccuracy.

But this fixation of the characteristic cavity pitch, or pitches, or difference constant, is not what we refer to, when we say that

"the only facts we know, and which we can rely upon, are those which involve the vowel as we hear it."

For regardless of the cause, and of the fact that we have not yet definitely agreed upon what it is, this much still remains to be said, viz.

that we all hear a certain vowel as a certain vowel. An *i* (ee) is an *i* (ee) to all of us. And an *a* (ah) is an *a* (ah) to each and every normal individual who has learned that vowel

in his native language. Where both are pronounced and heard distinctly we do not confuse them, whether prolonged or in words. And where a series of vowels is whispered every trained ear can place each in its respective niche; and will hear *i* (ee) as higher pitched than *e* (bay), or *ε* (eh) than *a* (ah), or *o* (oh) than *u* (oo).

That acoutic impression represents a known fact. It will be seen at a glance that it has nothing to do with

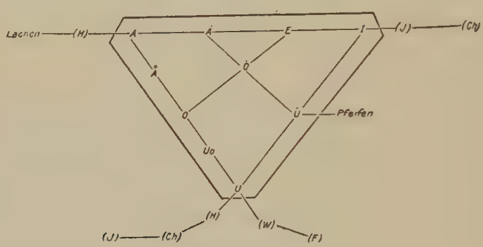


FIG. 292
Auerbach's Triangle (1909)

As the successor of Helmholtz he represents the great majority of those scientists who are accustomed to deal with facts as they are, rather than as our sometimes fantastic theories would like to make them. Practically all of these scientists base their classification on acoustic facts. "What the ear hears is a far more reliable criterion than what the tongue feels."

the Viëtor-Trautmann, disagreement. Nor with that of Passy-Rousselot. Nor the Sweet-Ellis. The author merely urges that we get back to the facts as a basis on which to establish our vowel schemes, phonetic alphabets, and speech theories. He undertook the X-ray experiments reported herein, in order to prove the validity of the tongue-arching vowel triangle. (His first series of X-rays placed according to the triangle is given herein as a curiosity, Figs. 258 to 270.) And now that it is clearly disproved, he cannot do otherwise than take the scientific stand, of urging that we discard both it and its implications in favor of something

which more nearly represents the facts. And the same thing may be said of physiological symbols in our phonetic alphabets, which fall along with the triangle, —e. g. signs used to show slightly more open (lowered) or closed (raised) tongue position, etc.

Violent changes are never wise. Our tongue-arching triangle scheme is one which has grown by evolu-

*a*rm;		*open-throat-n;*	
*a*sk;		*open-throat-w;*	
c*a*re, *a*m;	*o*dd, *a*ll,	*lfn, lfw;*	*lbw, lbn;*
*a*le, *e*nd;	*o*bey, *o*ld;	*mfn, mfw;*	*mbw, mbn;*
[f*e*rn. *e*ver;	[*u*p, *u*rn;	[*mfxn, mfxw;*	[*mbxw, mbxn;*
cv*e*, *i*ll;	f*oo*t, f*oo*d;	*hfn, hfw;*	*hbw, hbn;*
[*u*se (brief initial part);		[*hfxw.*	

FIG. 293

S. Porter's Arrangement in Webster's International Dictionary (1891)

The old pyramid with Sweet's terminology adapted. Note that the X-ray shows even his classification of the *a* (ah) series to be diametrically opposed to the facts. If he had stuck solely to what the ear hears, his arrangement would be a very good one. Then the right hand block would have been omitted.

tion to fit our imaginary theories. And as stated, the feeling for a triangular arrangement probably has some basis in fact. We have tried it with the *a* (ah) at the side, top, and recently the bottom. The latter is based on a physiological theory which the X-ray fails to confirm. But this is not true of all others. Some of the former were purely acoustic. And so far as the acoustic form is concerned, it may be based on fact.

Of the early triangles, having an acoustic interpretation upon which to base a classification, one of the

most clearly conceived, ingenious, and applicable right at the present time, was that of Lepsius.[1] Says he:

"There are 3 primary vowels as there are 3 primary colors. Like the latter they can best be represented by the analogy of a triangle. . .

a

i *u*

"The other vowels are formed between these 3 as all colors between red, yellow, and blue.

a

e *ö* *o*

i. *ü* *u*

(and) ". . . may be compared to the following pyramid of primary and mixed colors:[2]

red

orange *brown* *violet*

yellow *green* *blue*

So far as the series of vowels above given is concerned, it may be said that this acoustic vowel triangle scheme is entirely upheld by all modern research of which the author knows. And since this is true it would seem wise for us to give up our physiological scheme with the *a* at the bottom and if we must use a triangle return to some such a one as this. For if we consider the effect upon the ear, the vowel *a* may be said to be intermediate between the two extremes

[1] LEPSIUS, *Standard Alphabet*, 2nd ed. Williams and Hargate, London, 1863, p. 46. Parenthesis mine.

[2] op. cit. footnote, p. 47.

of *i* and *u*.[1] And the vowels which lie in between may literally be said to be "formed between these three as all the colours between red, yellow, and blue." Referring to musical tones in general, Helmholtz (who is recognized for his work both in optics and sound) has drawn a similar analogy for musical tones:[2]

"The phenomena of mixed colours present considerable analogy to those of compound musical tones, only in the case of color the number of sensations reduces to three, and the analysis of the composite sensations into their simple elements is still more difficult and imperfect than for musical tones."

Within the last three or four years the analogy of the spectrum has been used by Liddell as an arrangement scheme for the vowels. This he chose in preference to the current physiological vowel triangle, which he rather vigorously assailed in a private letter to the author. His spectrum looks something like this:

FIG. 294

M. H. Liddell's Concrete Acoustic Scheme

The pencil figures above and in between are mine; they merely show at a glance how many vibrations there are between each block. His arrangement represents one of the most distinct advances recently made in attempts to classify vowels. Every vowel is located in relationship to the other. Another such is that of Sir Richard Paget, Fig. 2. Crandall's is another Fig. 3. The author has indicated that the cavity tone frequency is not the only important factor in changing vowel quality and that may account for failure of investigators to agree on characteristic frequencies. But that does not prevent us from classifying vowels in accordance with our acoustic perception and other really known facts.

[1] MILLER, D. C. *Science of Musical Sounds*, 2nd ed. 1922. Macmillan, New York, pp. 226, 227, 230. 237. See Fig. 26 herein.

CRANDALL, I. B. *The Sounds of Speech.* Bell Technical Jour. Oct. 1925, chart, as shown in Fig. 3 herein.

[2] HELMHOLTZ, (*Ellis translation*) *Sensations of Tone* 4th ed. 1912. Longmans, Green and Co., New York and London, p. 64.

cf. Helmholtz, *Physiological Optics*, p. 227.

Such a scheme[1] serves admirably to indicate the gradual blending of one vowel into another. And personally the author finds much better success in its use with students, than in the use of the rather clumsy triangle. For Romance philology it may not serve to indicate the difference in changes which took place in so-called open and close vowels. But it remains yet to be proved that the so-called open vowel was actually more open in median section than the close vowel, and that this difference was the cause of the vowel quality differentiation, and the change. In due time it may yet be proved that there was some other distinction, and cause of the shift. In any event the present scheme caused us to leave the student's mind in such a haze in regard to other phenomena which did not fit in with its theory, that we could not make matters much worse by clarifying some of these, and throwing this one point back where it was, or where others leave it. Certainly it is difficult enough to look at the triangle scheme and see how the "open" *o*, that is the Latin free accented short *o* (in such a word as "rota") could split into a diphthong one element of which went to *u* (even if it did go to *uo* first) and the other finally get all the way around past the *a* and up to the *e* (becoming Spanish "rueda"). And the visualization of that process would be no more difficult where we use a purely acoustic blending scheme of the type Liddell proposes.

At any rate this idea of the vowels blending as do the colors whether we use the spectrum or Lepsius' triangle is one to which we would seem to be justified in holding. There can be no question that our hearing senses the vowels as being characterized by differences

[1] LIDDELL, M. H. *Physical Characteristics of Speech Sound.* Purdue University (Indiana), Bul. 16, Mar. 1924, p. 20.

in pitch. We would, of course, no longer agree with Willis[1] in ascribing but one set pitch to each of them. Scientists now quite generally agree, that our vowels may manifest pitch differences in more than one of their partials. But the more of these partials there are whose pitch changes we need to take into consideration, the more apt this idea of blending would be. Yet Lepsius was laughed at by those who urged the present scheme, and his idea was called a "curious conceit."

Now, it is the analogy to the three primary colors with which we seem to be justified in crediting Lepsius. The triangular scheme with the *a* at the top and even the idea of blending is much older, as stated above. We trace it much farther back than Chladni, in his "Traité d'acoustique" (1809). It will be noted that even at that time the scheme represents what the ear hears. And at the same time, it provides an ordered plan which serves to indicate vowel shifts and changes which are known to occur.

Not that they are all represented. *I* is not included, but he is applying his scheme to French, so its absence is not due to a deliberate suppression. In the present physiological vowel triangle applied even to English, it is also customary to omit this *I*.[2] But in our case such omission is reprehensible and is probably indulged in for the most part in order to keep our students from asking embarrassing questions as to why this vowel does not conform to the theory. The progression in pitch is quite regular, so long as we do not insert this *I*. As soon as we do, it creates a audible zigzag. As does the insertion of the *ə* or *U*. What we

[1] WILLIS, *On Vowel Sounds.* Trans. Camb. Phil Soc. 1830, III., p. 231.

[2] RIPPMANN, Walter. *Elements of Phonetics.* 7th ed. E. P. Dutton, N. Y., p. 28, 29.

then hear gives us an auditory impression which the average individual hears as something like:

i		*e*		*æ*		*ə*			*U*		
	I		*ɛ*		*a*		*ɔ:*	*o*		*u*	

It will be noted that in the lower row are what might be called "mellowed" or "deadened" vowels, and in the upper row the "clear" "bright" or "metallic" vowels. So far as the front series is concerned, the lower row includes the so-called "open" or what Sweet called "wide" vowels, and the upper the so-called "closed" or what he called "narrow" vowels; and the lower have sometimes been called "lax" and the upper "tense" vowels. These X-rays would lend more justification for the latter, but again the author has to reiterate that the sooner we get away from physiological terms and turn to the acoustic or "fact" terms the better off we will be. A piano string struck with a soft felt hammer gives a "mellow" tone and everybody knows what that means — the classification has basis in fact. If the same string is struck with a hard wooden hammer, the tone produced is "metallic"; this term likewise has basis in physical fact, and everybody understands what it means. Their usage for front vowel pairs, or for vowel qualities in general can therefore be justified. But is there any need of making such distinctions between pairs. Each vowel is a vowel, and that with a complete entity of its own. Our distinction is a heritage from the old Latin days, when there may have been more need for the differentiation which they designated by the terms "short" and "long."

If we must have a scheme which will provide for such a differentiation without the false implications involved in a single triangular leg which intimates a

regular progressive change (which the facts do justify when all the fine nuances are thrown in) we might use an adaptation of some such scheme as that of Evans placing our "mellow" vowels on the lower line (instead of as he does here) and the "metallic" on the upper for the basic series, leaving the inferior part for the so-called indefinite or transition vowels like the ə (uh). His (1882) was:

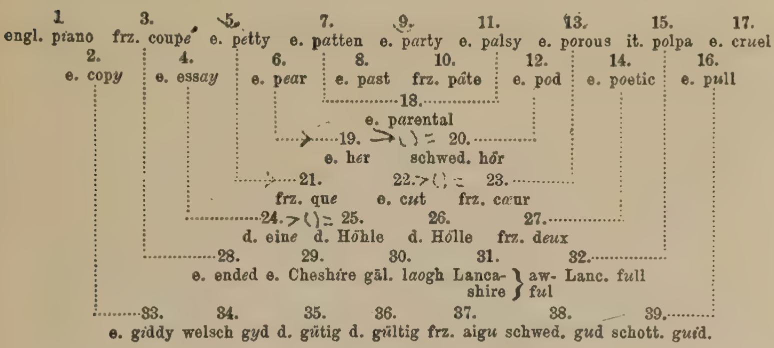


FIG. 295

Evans Acoustic Vowel Arrangement (1882)

This scheme needs some careful study if the reader is to understand it. The characteristic pitch progression for what he considers the basic vowels in the series is represented in the two top rows which are numbered in their order. He attaches no importance to the two-row arrangement, using it merely to save space. But if the author were adapting it he would place the "ringing" or "metallic" vowels along the top row, and the "mellow" or "dead" ones along the lower, as he did on page 308. The dotted lines indicate how one vowel may pass to the other thru the process of lip rounding, which we have represented by a penciled > and ( ) then an = sign.

So far as the purely physiological vocal organ placement and cavity dimension representations are concerned, the author cannot help but favor those proposed by Jespersen [1] in his Analphabetic diagram, and the

[1] JESPERSEN, O. *Articulations of Speech Sounds.*

See also his *Phonetische Grundfragen* translated in part from the Danish (1904) Teubner, Leipzig, p. 104 et. seq.

precise millimeter measurement plan proposed by E. A. Meyer.[1] The former would probably have received wider acceptance if the Greek symbols chosen had not been so hard to write and for the non-classical student to remember. For that reason we would rather lean towards a choice of letter markings which would suggest the organs involved; and to the use of a smaller number along the roof of the mouth, with a location of these at specific points after you pass the alveolar ridge. If we coupled this Jespersen scheme with Meyer's proposal for exact millimeter measurements in lieu of the former's arbitrary numbers, we could give a portrayal of the cavity dimensions which would serve the scientist wherever he were, and that very much better than the Sweet-Bell box system which we dealt with in the Chapter on Tongue-Position.

We have reproduced the life size X-ray shown in Fig. 33 as a reduced cut in Fig. 265, on this latter we have engraved those diagram symbols or rather letters, and underneath we have given an explanation. We may now either begin at a given point and take measurements at 1 cm. intervals following always parallel lines, as we did for our computations in Chapter XI above on Cavities; or we may take measurements in millimeters as before but only at the points indicated at the letters in order to facilitate matters and give a more sketchy view; or we may strike a mean and where too widely spaced take a measurement half way between any two letters. In all cases we must not, of course, forget to add a measurement of the length of the tube, or separate parts thereof where this seems to be called for. And where possible we should have the breath pressure, and some information about the "metallic" or

[1] MEYER, E. A. The outstanding phonetician of Upsala and Stockholm, Sweden, in his report on plastographic analyses. *Untersuchungen über Lautbildung*, Viëtor Festschrift Elwert (1910) Marburg. p. 172, etc.

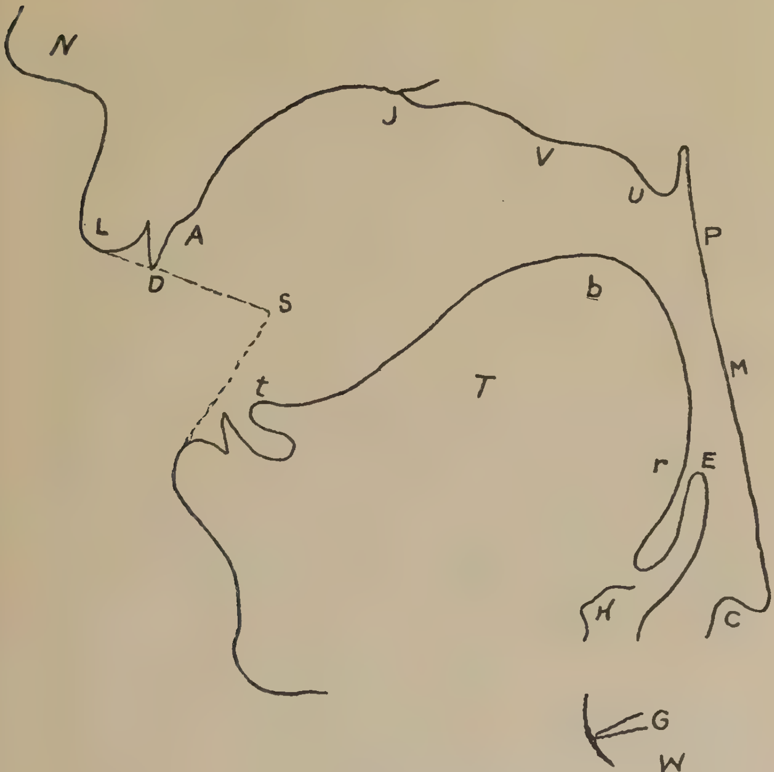


FIG. 296

Reduction outline cut of the full-size X-ray shown in Fig. 29. It is actually the *a* (ah) position taken by the Soprano subject 408, sung on a very loud note, and verging perhaps somewhat towards the quality for ɔ (aw). Used here to show substitution (of common everyday easily written letters suggesting the organ involved) for Jespersen's Analphabetic Symbols, which provided a splendid idea for classification, but was unfortunately not enough used perhaps because of the difficulty of writing and remembering the Greek symbols he utilized. Here N=Nasal; S=Lip Spread; L=lip (upper), l=lower lip; D=Dental; A= Alveolar; J=Juncture of Hard and Soft Palate; V=Velum; U=Uvula; P=Pharynx (upper), M=Mid Pharynx, C=Cornu or Lower Pharynx; T=Tongue; r=root of tongue, b=back of tongue, t=tip of tongue; G=Glottis; W=Wind; E=Epiglottis; H = Hyoid Bone.

"mellow" quality present in the sound produced; besides interior larynx information would be of decided value, for the reasons the author cited in his study thereof. We would then be provided with usable physiological information. The letter symbols would serve to orient the reader and the computations would give him some idea as to the cavity dimensions.

So far as the author is concerned however, his preference leans rather to an acoustic classification. Let us turn therefore to a consideration of such of those as will best serve us.

If we took the acoustic triangle Lepsius proposed with the *a* (ah) at the top, and turned it around to the side, we might still retain the same idea of blending of three primary colors, for our vowels, and at the same time incorporate some of the other known physical facts, and include some of the less disputed physiological possibilities where one thought it desirable. It would then appear thus:

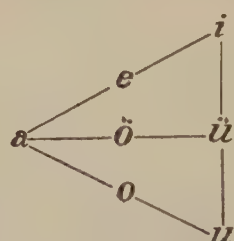


FIG. 297

This would represent the known pitch progression for the 5 so-called "cardinal" or "Latin" vowels, ranged from high to low:

i
e
a
o
u

And it would likewise show the fact that there are three pivotal vowels:

$$\begin{array}{cc} & i \\ a & \\ & u \end{array}$$

mixtures of whose tonal color produces the intermediate vowels:

$$\begin{array}{cc} e & \\ \ddot{o} & \ddot{u} \\ o & \end{array}$$

etc., "just as we obtain mixtures from the three primary colors" if it is desirable to use the analogy of Lepsius.

Any physiological application would seem to the author to be unwise. But the older interpretation of the triangle would appear to be less objectionable than our modern one, since the former provided for physiological causal positions which the X-ray analysis would seem to more or less justify. That is it indicates the arching of the tongue upwards towards the hard palate to "brighten" the vowels and make them more "metallic" through narrowing the channel and constricting the passage against hard surfaces and simultaneously distending the pharyngeal cavity from the *a* (ah) norm to *i* (ee) thus:

$$\begin{array}{ccc} & & i \\ & e & \\ a & & \end{array}$$

But it also shows the most common process of "mellowing" or "deadening" the quality, or making it more

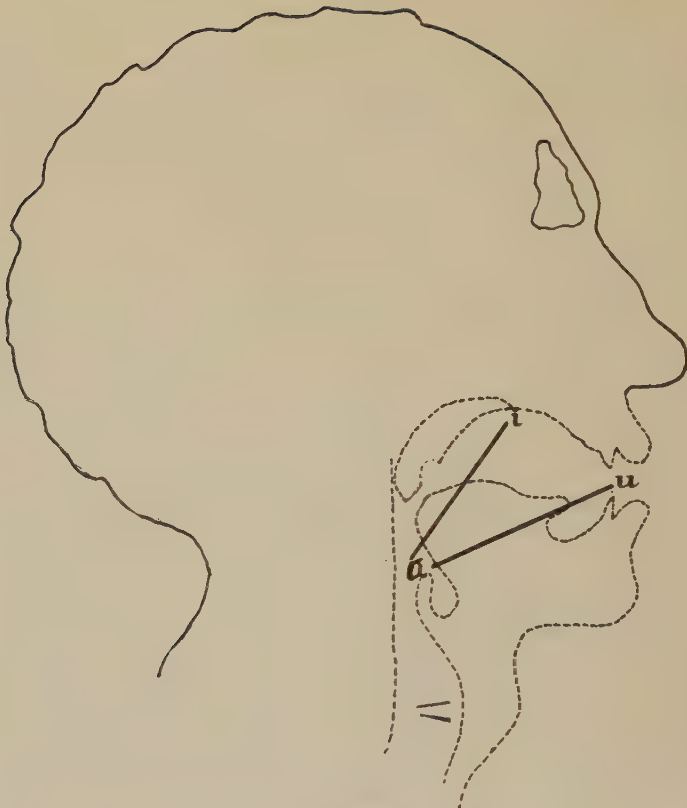


FIG. 298

Constriction against the hard palate for the *i* (ee) series; of the lips or velum for the *u* (oo) group; and of the epiglottis and tongue against the pharynx wall with elimination of the lower or laryngeal resonator for the *a* (ah) set; would appear to be the three most characteristic physiological factors involved in creating their respective vowel quality differences. An older triangle of a century ago made this postulate. (It is sometimes credited to Orchell but really antidates him.) That scheme is still widely used by philologists, grammarians, and other scholars the world over. And while the author does not favor any physiological terminology for, or classification of, vowel quality differences, he does not hesitate to say that this side *a* (ah) triangle is much more justified by the facts shown under X-ray examination than is our triangle with the *a* (ah) at the bottom. Hence for those who insist on a triangle he recommends the use of the above pictured scheme preferably with the addition of the physical law and acoustic fact application which is schematically indicated at the end of this chapter in Figs. 299 and 300.

"barrel-like" thru either closure of the lips, or distension of the pharyngeal cavity from the *a* (ah) norm to *u* (oo), thus:

a

o

u

It would show that in both cases, as we moved away from *a* (ah) to either *i* (ee) palatal or *u* (oo) lips, we might have both a narrowing of the front opening and a distension of the pharyngeal cavity. The narrowing would account for the decreased loudness in both *i* and *u*. And the palatal constriction for *i* (ee) would partially account for the increased "metallic" quality, since it is a hard surface; whereas the lip or palatine arch soft surface constriction would account for the increased "deadening" or "mellowing" of the tonal quality in the *u* (oo). If the user cared to insert other (especially the so-called "open") vowels he might. The author would not be the one to recommend it here

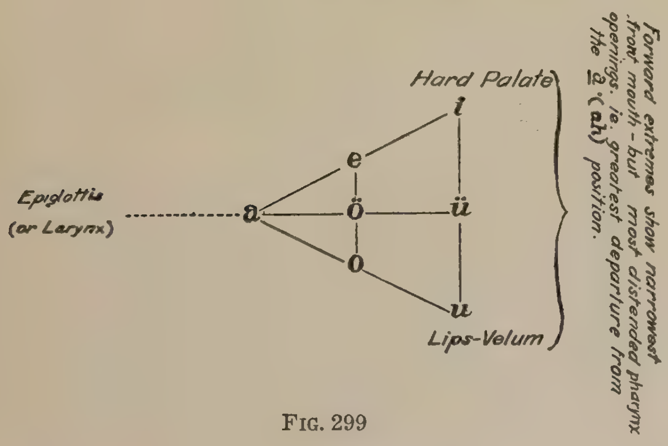


FIG. 299

any more than he did for the tongue-arching triangle. For the "open" quality must be due to something else besides "opening."

If it is desirable to insert descriptive terms, those utilized for the triangle before it was given its modern tongue-arching theory and application, could be used. The three angle points then indicate the three physiological determining factors as indicated by the points controlling: constriction and distension of cavities, or involvement of hard and soft surfaces as shown in Fig. 299.

Or the acoustic effect could be indicated by the use of some such terms as the following:

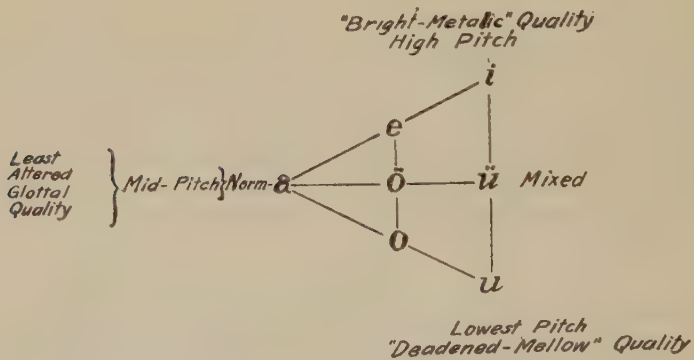


FIG. 300

The kind of Vowel Triangle the author would recommend as more nearly conforming to the facts, if he were inclined to sustain the triangle type of scheme. Here is a good place to call attention, however, to the fact that the "dull" or so-called "open" vowels cannot be ranged along the intermediate positions of such a diagram, if one desires to adhere to an accurate expression of the facts. This is particularly true of the physiological aspects represented in Fig. 299. Neither can the so-called "indefinite" or ə (uh) series be located hereon if one has consideration for careful adherence to the facts. Some such diagram as the box shown in Fig. 282 could better be adapted to serve our purposes in this respect.

CHAPTER XIV

CLOSE–OPEN; NARROW–WIDE; TENSE–LAX;

METALLIC–MELLOW; CLEAR–DEAD; BRIGHT–DARK; RINGING–DULL; HIGH PITCHED–LOW PITCHED —WHICH ARE THE MOST ACCURATE DESCRIPTIVE VOWEL TERMS?

"Within each series, vowels are divided into **open and closed** according to the greater or less distance which each one of them requires between the tongue and the palate; the most open vowel is of course the *a*; departing therefrom, and dependent on the distance which the tongue is raised towards the front or the back, the vowel which is pronounced becomes more closed than the *a*; . . . and above there may further be produced other variants *e*, *o* with less distance between the tongue and the palate than for ɛ, ɔ," which are more open than *e*, *o*. "The most closed palatal vowel is *i*, and the most closed velar, *u*.

"The tongue can take a position intermediate between that for *u* and that for *o*, producing a very closed *o* or an open *u*; in the same manner we may postulate vowels intermediate between ɔ and *a*, between *a* and ɛ, etc., which as a matter of fact are found in the pronunciation of many languages."

— Navarro Tomás[1] (1926)

"**Narrow and Wide.** This important distinction applies to all vowels: every vowel, whatever its position in the scale, must be either narrow (tense) or wide (lax) . . .

[1] NAVARRO TOMÁS, Tomás. Pronunciación Española 3rd ed. Madrid (1926) p. 36. Free translation mine. The characters he used, placing under the letter the dot for closed and hook for open vowels are substituted by the symbols used herein, representing approximates and the general idea rather than the exact equivalents.

Lateral Cross-section Palatograms

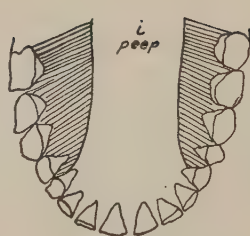


Fig. 301

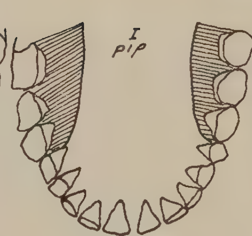


Fig. 302

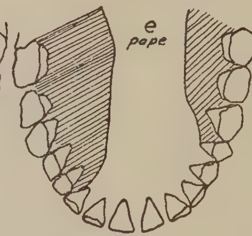


Fig. 303

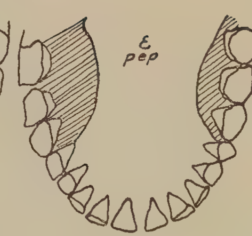


Fig. 304

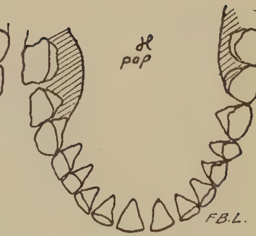
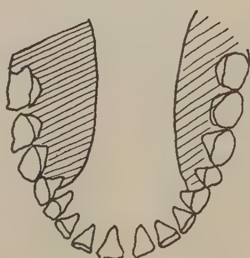


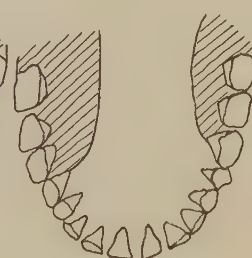
Fig. 305

Vowels pronounced in words

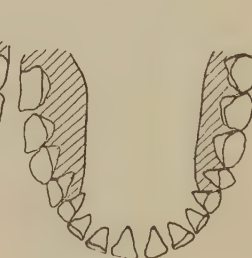


i
Fig. 306

ɪ
Fig. 307



e
Fig. 308



ϵ
Fig. 309

æ
Fig. 310

Vowels isolated and prolonged by same subject

All these palatograms from Figs. 301 to 539 are reduced by exactly ½. So 5 mm. on the scale = 10 mm., or 1 sq. mm. = 4 sq. mm. The reader is thus enabled to compute the total area, or dimensions at any point, for himself. Any two vowels or any subjects are also thus comparable at a glance. So here for example it will be noted that the same subject produced an *æ* (pap) with a front cavity in Fig. 310 which was more narrow (or closed) than the cavity he used for *ɪ* (pip) of Fig. 302 and about as much as for his *i* (peep) Fig. 301.

> French *i* in *fini* and English ɪ in *finny* are both high-front vowels, but the former is narrow (*i*), the latter wide (ɪ). In passing from (*i*) to (ɪ) the passage between the front of the tongue and the palate is further narrowed, not by raising the whole body of tongue, but by altering its shape; in a narrow vowel the tongue is bunched or made convex lengthways, and there is a feeling of tension or clenshing; in wide vowels the tongue is relaxed and comparatively flattened."
>
> — Sweet[1] (1910)

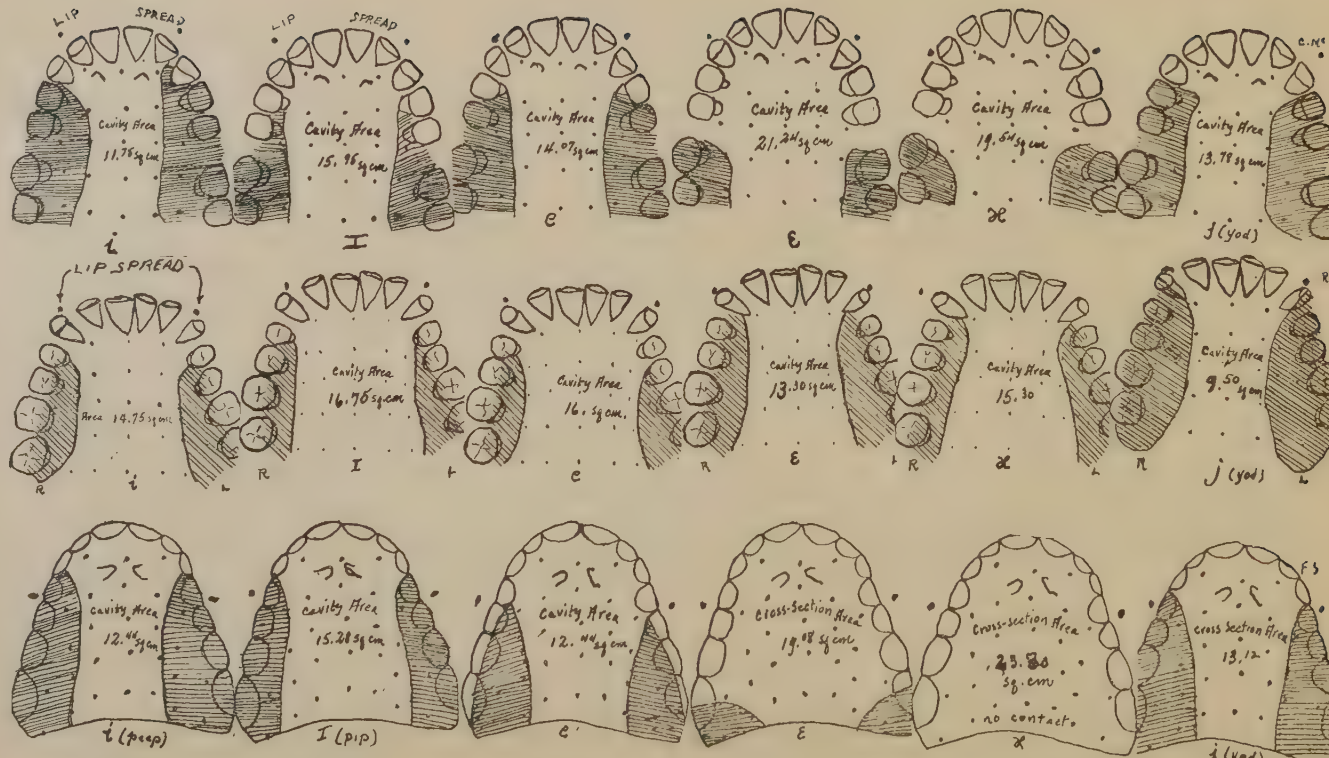
Tomás Navarro Tomás in the quotation given above, states the theory of open and close vowels more clearly than any other author immediately available. As a matter of fact, most writers who use the terms seem to have but a hazy idea as to what they are meant to imply. One cannot help but feel that on the whole, they are most of them really using these terms in an acoustic sense, thinking mostly of the sounds they represent in their experience, rather than any definite theory as to precise physiological cause.

It is all too common to find those who use the words, making no distinction at all, or but a vague one, between "open and closed," "narrow and wide," "tense and lax," "dull and clear," "high-pitched and low-pitched," or the innumerable other such expressions. Yet each of those pairs just mentioned stands for an entirely different conception or theory, and represents facts, all quite unlike those involved in the other pairs.

First of all we need therefore, to define what the terms used in the caption to this chapter mean, and indicate the facts and theories they are supposed to represent.

The first three pairs (viz. "open-close," "narrow-wide," and "tense-lax") all represent what were sup-

[1] SWEET, Henry. The Sounds of English. Oxford Press (1910) p. 27.

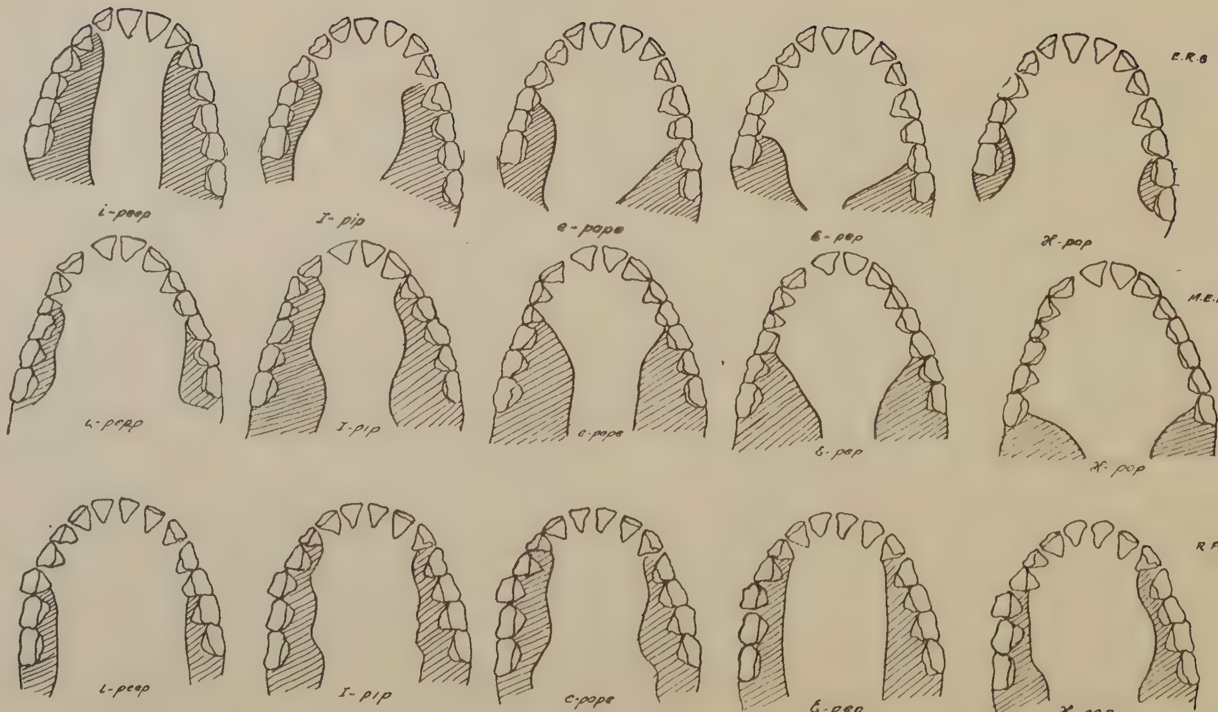


Figs. 311, 317, 323 — Figs. 312, 318, 324 — Figs. 313, 319, 325 — Figs. 314, 320, 326 — Figs. 315, 321, 327 — Figs. 316, 322, 328

posed to be physiological causes of vowel quality differences.

The second line of this chapter's caption gives acoustic terms used to designate qualities manifest in sounds. And these represent by far the most reliable contrasting terminology pairs, which could be used by any and all to classify vowels. The first term in each pair would be used to designate the tonal quality produced when a piano string is struck by a hard hammer thus favoring the high pitched "metallic" partials or notes. Such are also the vowels *i* (ee) and *e* (ape). The second one of each pair indicates the opposite quality — that heard when the same piano string is struck by a soft felt hammer, thus damping the high piercing partials and favoring the low-pitched "mellow" harmonics in the sound. The vowels *u* (oo) and *o* (oh) are of this type. Since these terms in the second line of the caption to this chapter stand for facts and qualities we all hear the author prefers them to the physiological ones used in the first line, which try to classify on the basis of purely imaginary and sometimes highly fantastic theories referring to cavity and muscular influences about which we still know but precious little. For that reason the author would like to see the terms **open-closed, narrow-wide, tense-lax** discarded in favor of the more reliable ones in the second line, but he does not anticipate that they will be for some time. So perhaps we had better consider the least objectionable.

The terms **open** and **closed** (or open and close, preferred by some) refer to the perpendicular opening between the tongue and the roof of the mouth, measured along the median or center line, which would correspond to the tip of the nose. As indicated in our chapter on tongue position, there is much vagueness and difference of conception among those who use even



Figs. 329, 334, 339

Figs. 330, 335, 340

Figs. 331, 336, 341

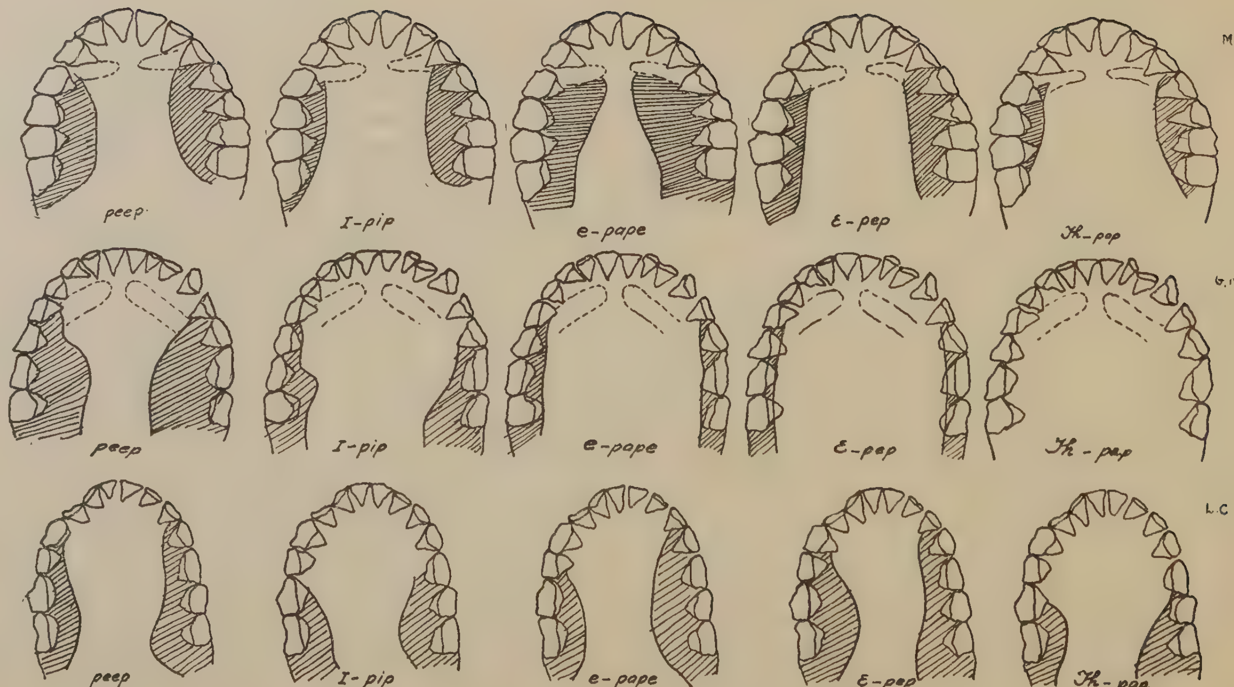
Figs. 332, 337, 342

Figs. 333, 338, 343

this one simple set of terms. Some think of the point of highest tongue-arching which is supposed to increase or decrease the length of the front buccal or mouth cavity. Therefore the quality manifest in the vowel *i* (ee) was, according to this theory, supposed to be created by a short in length and hence very high-pitched resonator formed when the tongue arched well up towards the teeth against the alveolar ridge thus making a very short tube extending from that little ridge you feel with the tip of the tongue, to the teeth. This short tube would then be conceived of as functioning like an organ pipe. And we know that the pitch of such a pipe is dependent solely upon its length (disregarding of course the diameter of openings, and incidental characteristics of stopped pipes).

See the traditional tongue position in Fig. 60.

Most of those who advanced this view, disregarded until very recently, the throat cavity formed back of the point of arching, and generally postulated an abrupt sloping downward of the back tongue from the supposed arch against the alveolar ridge towards the larynx. An exception must be noted for Lloyd, those who followed him, and others who like him, were better grounded in the basic scientific principles of phonetics. They not only insisted on the importance of this back cavity, but acknowledged the fact that it might possibly function as an irregular or total-capacity resonator. However, the language teachers and philologists generally, who classified vowels according to point of tongue arching, thought for the most part, only of the front buccal cavity; for it was the front mouth which was pictured in the tongue-arching vowel triangle. The quality of the *i* (ee) was supposed to be due to the influence of a short cavity, and that of the *u* (oo) to a longer one.



Figs. 344, 349, 354

Figs. 345, 350, 355

Figs. 346, 351, 356

Figs. 347, 352, 357

Figs. 348, 353, 358

Compare Figs, 60 and 67 for this traditional view.

Of course there were others who understood the real theory which is apparent in the tongue-arching triangle, and coupled with the idea of increasing length, one of simultaneous and progressive widening of the cavity, as the pronunciation passed thru the series:

i (ee), *e* (ate), *a* (ah), *o* (oh), *u* (oo).

Then there were some who thought of the cavities as functioning like irregular or spherical resonators, and considered only its variation in total air volume, without respect to any particular point of arching.

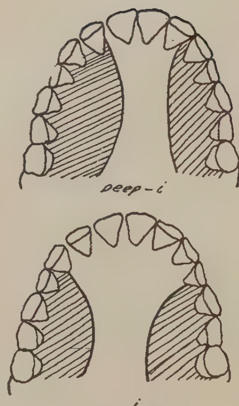
But after all we must acknowledge that the great majority who were so glibly using the terminology, had no definite theory at all in mind, but applied the triangle scheme, parrot-like, in a very vague hazy way, to certain sounds which their ears distinguished. And confusion was rampant because they were thinking in terms of acoustic fact and using physiological phantasy to express the idea — a fantastic triangle theory and accompanying terminology whose basis in the laws of physics they did not understand and hence applied so blindly that confusion multipied.

This latter situation was no doubt partly due, to the condition Sweet condemned in his introduction to the work above cited[1] where he stated (in 1907) when he spoke of the manner in which language teachers had taken up the study of phonetics:

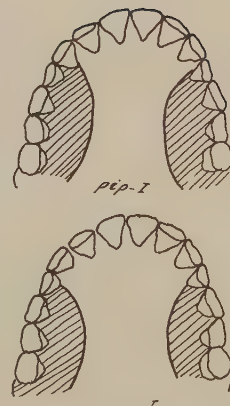
> "Many teachers who used to profess not to know what phonetics was, forthwith announced classes in it. And then came a flood of worthless publications on phonetics — most of them uncritical compilations from foreign works."

The world suffers from the numbers of that type of so-called "phonetician." In the United States there is hardly a college, however mediocre, but that has at least one teacher who essays to give a course in phon-

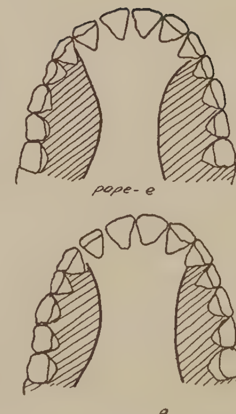
[1] *Op. cit.*



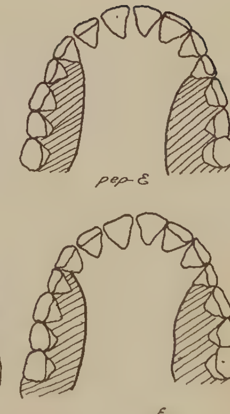
Figs. 359
364



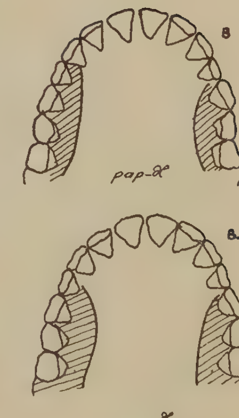
Figs. 360
365



Figs. 361
366



Figs. 362
367



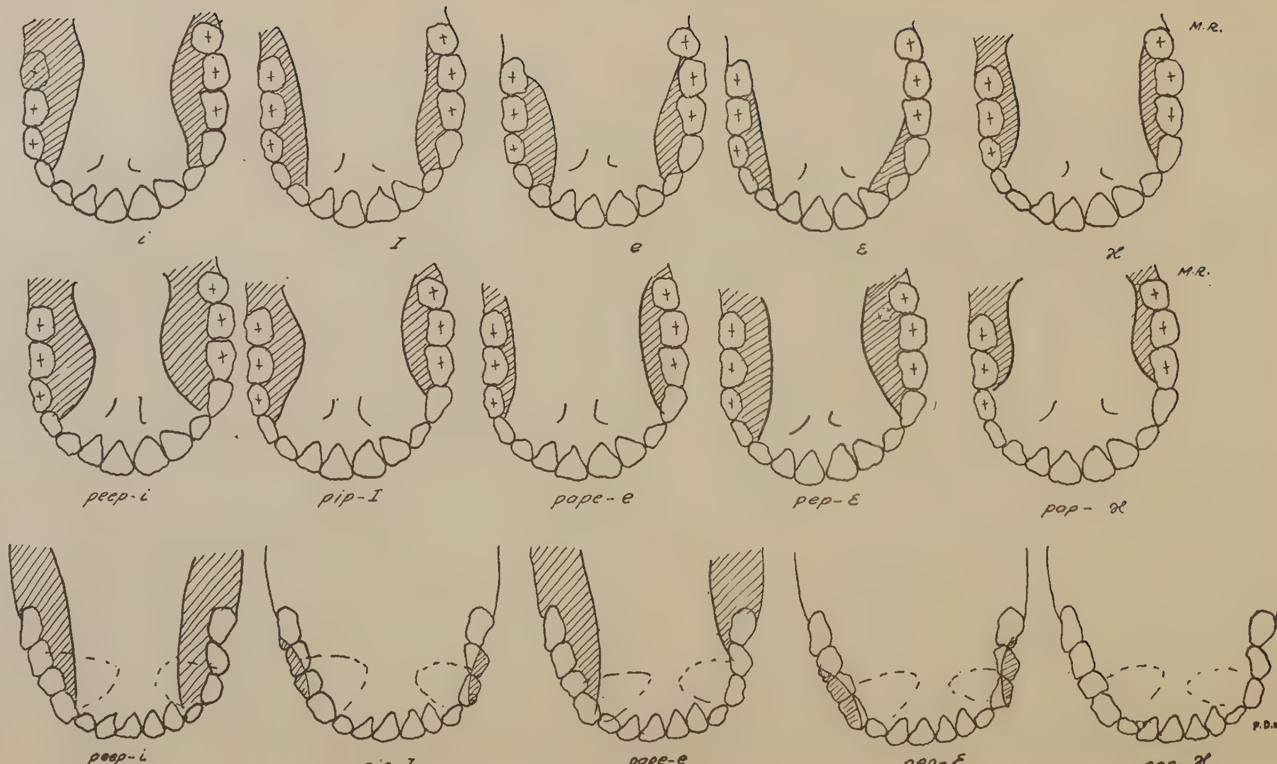
Figs. 363
368

The initials of the subject are generally placed up to the right against the front teeth. These will show when the same vowel has been registered by the same subject at different times under different conditions. In all cases one row shows those in short words between labial consonants and the other when isolated and prolonged, as in this plate; that on p. 318; top two p. 328; lower two p. 330; upper two p. 332; 335; 338; 341. The variations cannot be without significance in throwing doubt on open-closed and narrow-wide theories traditionally used to account for vowel quality differences.

etics of some kind, though usually without any preparation whatever therefor, or at best after having attended a one- or two-quarter course usually under some "scholar" (?) of the same kind. In private instruction there are others. And all commonly take refuge in the assertion that they are "practical phoneticians." It is a woefuly unfortunate situation, but one fostered by our present school system. Naturally where such a teacher lacks background in the physics, and physiology, not to speak of the other basic facts of real phonetics, his ideas bearing on this question of "open" and "closed" vowels, as well as other aspects of his subject, must of necessity be sketchy, unclear, and for the most part erroneous. And it follows that he or she will hammer the same type of conception into the student.

On the other hand, the vagueness and misapplication, current in the usage of the terms, may in a large measure be due to their antiquity. For we well know the inherent human tendency to hold tightly to a thing we are accustomed to use, and force its adaptation to whatever we want to use it for no matter how conditions change, and that, regardless of whether something else would serve us better. Our modern system of spelling in English is evidence enough of that tendency. And the usage of such traditional terminology as that involved in the words "open" and "closed" falls in the same category. There can be no doubt but that we have given them an entirely different meaning at several different times, and some confusion must therefore in consequence, inevitably result.

So far as those who were interested in Romance languages were concerned, these terms "open" and "closed" were for the most part applied to a distinction between the sounds which approximate the English

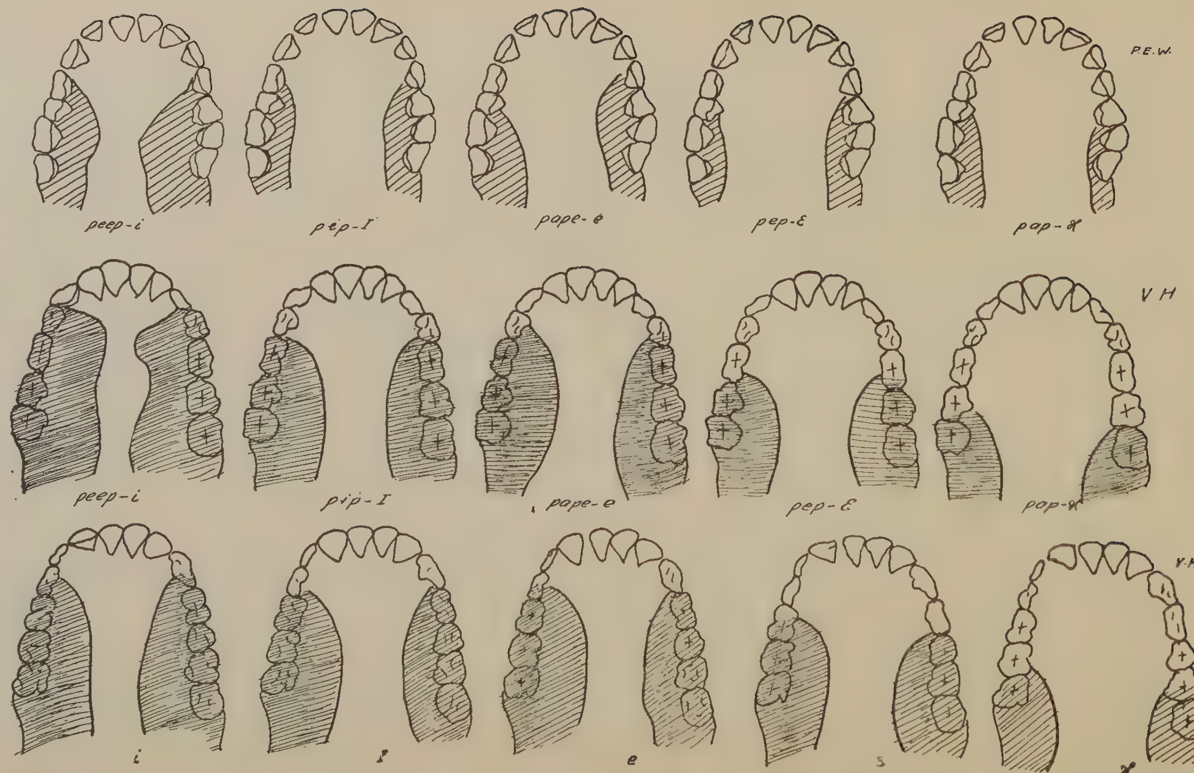


Figs. 369, 374, 379 — Figs. 370, 375, 380 — Figs. 371, 376, 381 — Figs. 372, 377, 382 — Figs. 373, 378, 383

ɛ (pet) as compared with *e* (pate); or the ɔ (bought) compared with *o* (boat).

It is probable that as originally used, the terms applied to the mouth opening. The user could see that the lip opening was more closed for *u* (oo) than for *a* (ah). Hence he called the *u* (oo) "closed" and the *a* (ah) "open." The analogy evident as between the sounds these terms were supposed to represent, and those in Latin which the older classification of "long" and "short" indicated, may have brought about an attempt on the part of the thinking scholar to explain the vowel quality they had been so classifying, by attributing it to the mouth opening. And as we know, this opening was very apparent in jaw and lip movement.

The pivotal position which *a* (ah) occupies in the series must strike any observer; especially where the one he is watching, pronounces the isolated prolonged group: *i* (ee), *e* (ate), *a* (ah), *o* (oh), *u* (oo). If the speaker is using one of the Romance languages, such as Spanish, French, or Italian, where the lips manifest a more decided back and forward movement than in English, the corners of the mouth may also appear to be stretched farthest back for *a* (ah). Then we have the narrowest opening for *i* (ee) and *u* (oo) and the widest for *a* (ah), with the *e* (ate) and *o* (oh) taking an intermediate position; and since the corners of the lips are seen to stretch backwards in the course of the progression, from *u* (oo) to *a* (ah) and on to *i* (ee), it was perfecty natural that a triangular conception should have grown up. In what we now call the "front" series of vowels, from *i* (ee), thru *e* (ate), to the *a* (ah) the opening was evidently conceived of as being manifest in the jaw movement or spread between the teeth. And in what is now commonly called the "back"



Figs. 384
389
394

Figs. 385
390
395

Figs. 386
391
396

Figs. 387
392
397

Figs. 388
393
398

series from *a* (ah) thru *o* (oh) to *u* (oo) it was ascribed to the lips.

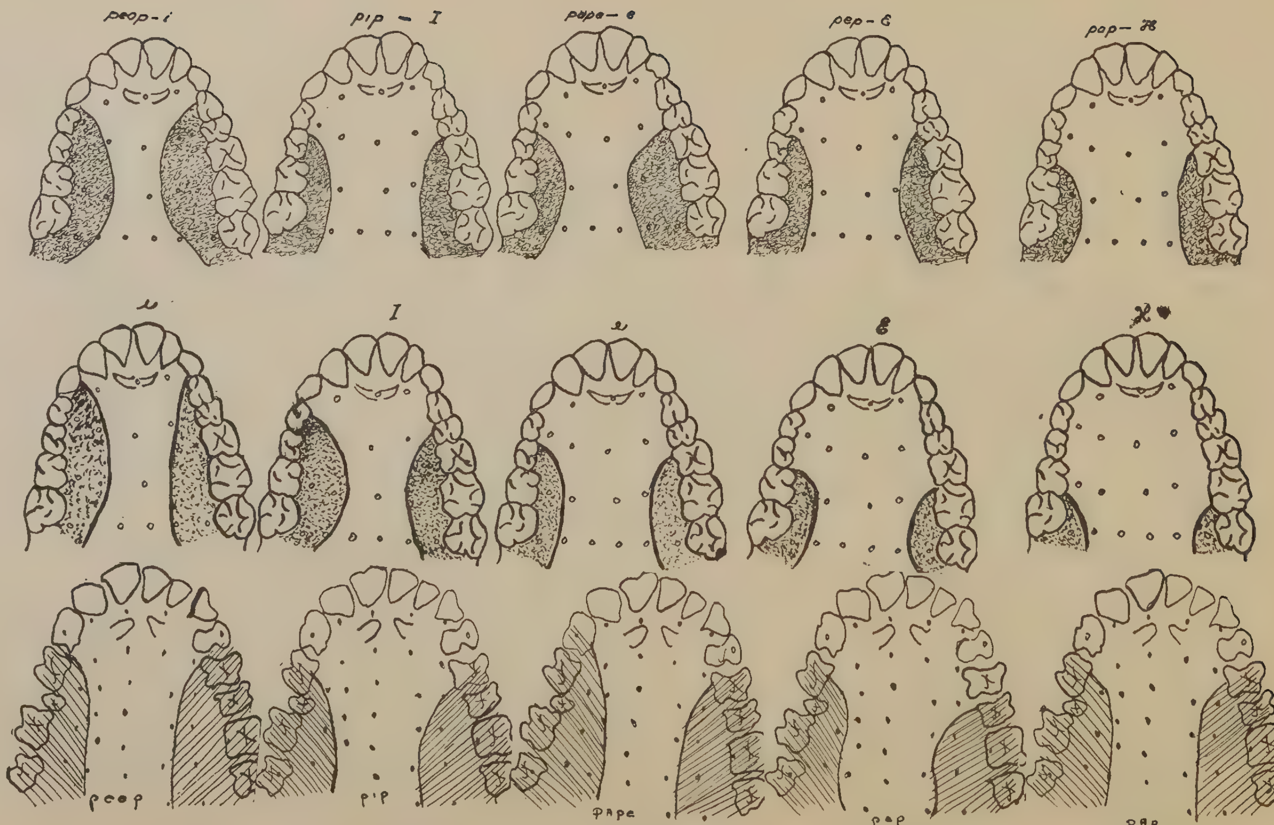
For both *i* (ee) and *u* (oo) the opening was the most closed, and for the *a* (ah) the aperture was the most open. The *e* (ate) was more open than the *i* (ee), and ɛ (pet) more open than the *e* (pate) ; whereas a similar variation in the opening of the back series could be noted, the *o* (oh) showing the lips more open than the *u* (oo) and the ɔ (aw) more open than the *o* (oh). So that the triangle seemed to be justified, showing

```
Lips            Jaw
 u................i........closed

   o............e..........less closed

     ɔ........ɛ.............open

         ɑ.................most open
```

But those who thought and observed for themselves soon discovered that this jaw opening was purely incidental. They shortly noted that it was possible to take almost any jaw position and produce any of the vowels; and that the same thing might be said of the lip opening. Then the scheme came to be applied to the movements of the tongue, and has so persisted to the present time.

Yet our X-ray examination shows that there is little more justification for the tongue-arching conception, than there was for the lip and jaw postulate. And if the tongue-arching vowel triangle is proved to be fallacious, the terms **"open"** and **"closed"** must likewise go into the discard.

At the end of our Chapter X on the Tongue-arching Vowel Triangle — a Fallacy, we have considered the evidence in detail. We note that even Viëtor, the most vigorous sponsor for this modern triangle child of his,



Figs. 399
404
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Figs. 400
405
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Figs. 401
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Figs. 402
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Figs. 403
408

finally acknowledges[1] in his comment on the X-ray and plastographic experiments of Meyer that they

> "prove all of our former conceptions in regard to tongue articulation to have been erroneous,"

and calls attention to his disturbing observation that in these experiments, he found

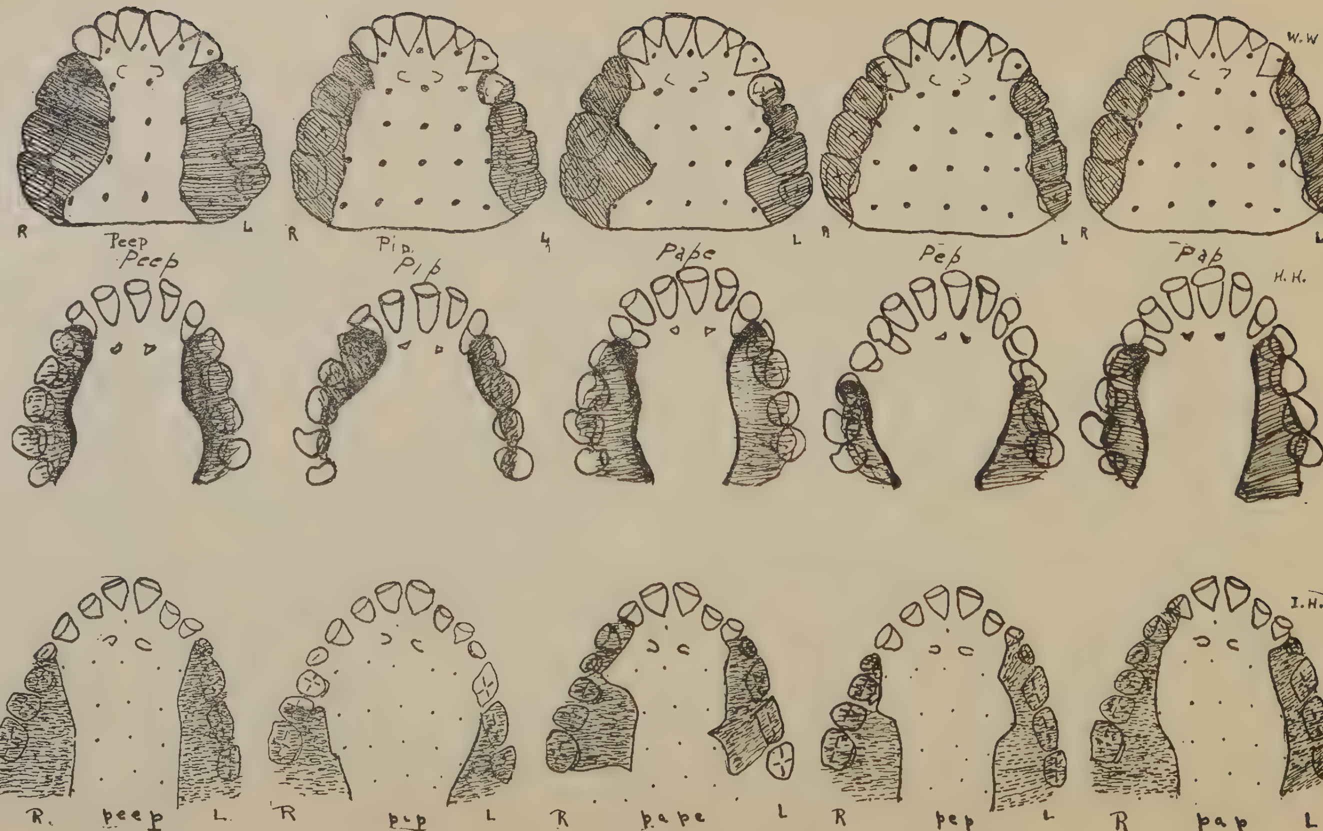
> "*I* to be more "open" than *e*, and as between certain languages finds the *e* to be more "closed" than *i*."

It will be remembered we stated that "this need not be ascribed to the fact that those experiments were dealing with different languages. If that were true it would mean that the southern Englishman, or north German would be constantly hearing *e* when the Italian used *i*. That is if the Italian said "si" they would be hearing "se." Our X-rays confirm this observation and go farther. They show that it is very common for the same subject to take a tongue position for *I* (pip) which is more open than the *e* (pape). The tables in Chapter XI make this very evident. As a matter of fact the *I* (pip) is sometimes more open than ɛ (pep) ; and in some cases the *I* (pip) is actually more open than *æ* (pap) all in the pronunciation of exactly the same individual.

Then so far as the back vowels are concerned, there is an even more shocking lack of conformity with our traditional designation of "open" and "closed" vowels. The tables make that very evident, and there is no necessity for citing the deviations in detail, for there is actually more deviation than conformity.

The author therefore has no hesitancy in saying that we should discard the terms "open" and "closed" in describing vowel quality differences. For they can in no sense of the word, be considered as descriptive of the cause of such differences.

[1] VIETOR, *Zur systematik der Vokalartikulation*, Miscellanea Phonetica, Association Phonétique Internationale to commemorate the 25th year of "Le Maître Phonétique" 1914.



Figs. 414 419 | Figs. 415 420 | Figs. 416 421 | Figs. 417 422 | Figs. 418 423

Lateral Cavity Dimensions from Palatograms

The palatograms given in this chapter follow a technique developed in the experimental phonetics laboratories of Ohio State University which the author has the honor to direct, and are the contribution of some of his advanced students. The process used makes it possible to produce them rapidly, and check and recheck the results in a way not heretofore attempted. The author feels therefore, that their accuracy in numerous detailed ways, surpasses that we have been accustomed to ascribe to such experiments. But into these aspects we need not enter here.

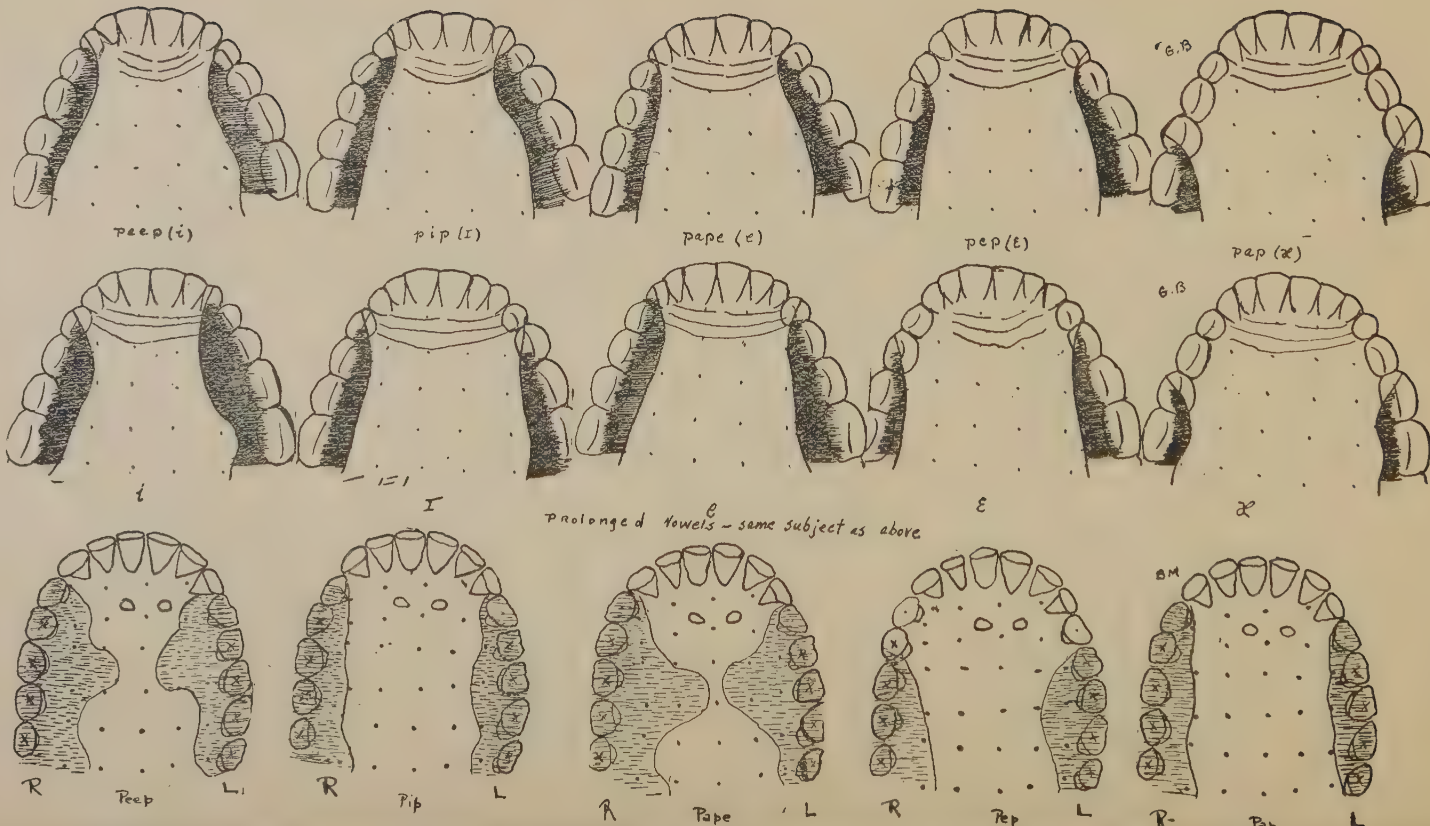
The three plates beginning with Figs. 459, 464, and 469, cover respectively the pronunciation of a Peruvian; another born of Castilian parents, and educated from childhood to maturity in Santander Spain, but a native of Cuba; and the last an Argentine Spanish American from Santa Fé with a rather more universal pronunciation of Spanish free from the dialectical peculiarities so often localized; all young men in the twenties.

With those exceptions the rest are from a homogenous Mid-East United States English speaking group, all with pronunciations which are essentially alike. All are young people of approximately the same age as the above, the males showing in Figs. 301 and 306; 344; 349; 311; 317; 384; 409; 429 and 434; 518. Since no dialectical or speech defect peculiarities are present in the group, no further case histories need be cited.

These palatograms show the horizontal section or lateral cavity opening for the series of front vowels:

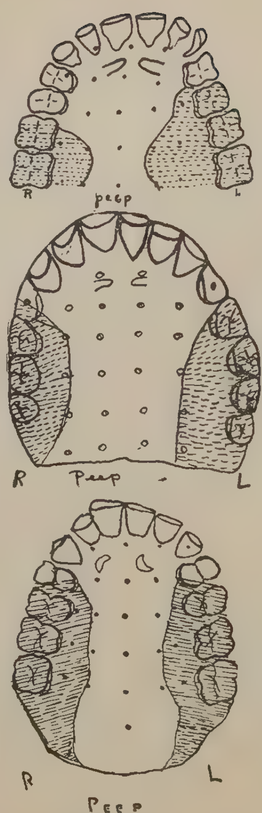
i (peep), *ɪ* (pip), *e* (pape), ɛ (pep), *æ* (pap).

They are all reduced to ½ the original size, and hence can at a glance, be compared with each other in



Figs. 429 Figs. 430 Figs. 431 Figs. 432 Figs. 433

the same series, or with those of other subjects herein, or with those published by other authors where the amount of reduction is stated. In many cases the lateral lip spread is also given, showing as two dots against the outside edge of the front teeth. In others the total cavity square area represented by the white surface between the shading has been stated in figures. The reader can easily compute those that are not, by laying a piece of transparent millimeter cross-section paper over each one and spotting the squares. Since the reduction is to ½ the natural size, 1 cm.= 2 cm. or 1 sq. mm.= 4 sq. mm. The dots which appear scattered over the surface of some figure, show the type of perpendicular arch. On the original false palate they were located along parallel and right-angle lines at intervals of 1 cm. So when projected on a flat plane they show in distorted order thus indicating the palatal arch. Some palates are quite regular like that of the subject shown in Figs. 317 to 322, and in this case very flat. The one below it Figs. 323 to 328, is however evidently irregular and high. This is shown in the irregular spacing which finally shows in the flat projection. This dot arrangement could have been given for all, but appeared to be somewhat confusing to the average reader and hence was omitted. The uniform shading used in some will show that they have been copied from the originals over mimeoskopik light. This was necessary in order to put all figures in the same order of arrangement. But each set has been originally made by a different carefully trained experimenter, who was purposely kept ignorant of any preconceived idea as to what should appear. The author believes that this is the first time such care has been exercised in order to avoid the subjective element which might well enter into such experiments. Yet all have been



Figs. 444
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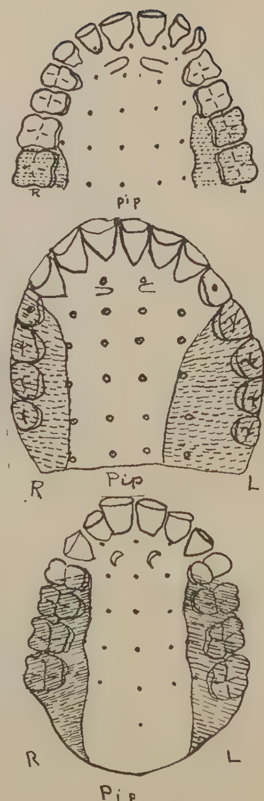
454



Figs. 445
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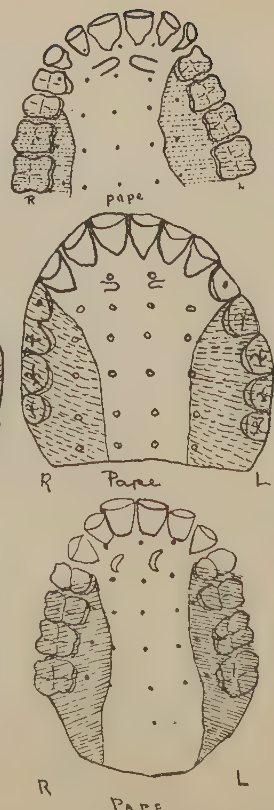

Figs. 446
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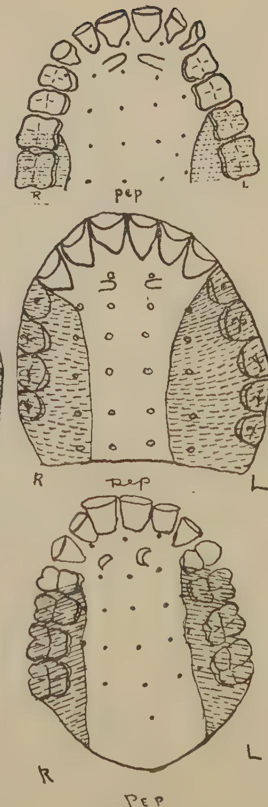
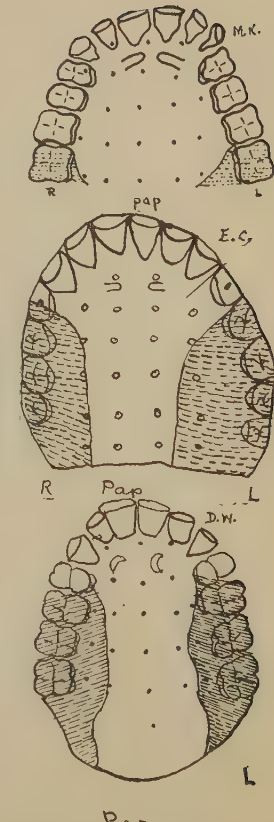


Figs. 447
452
457



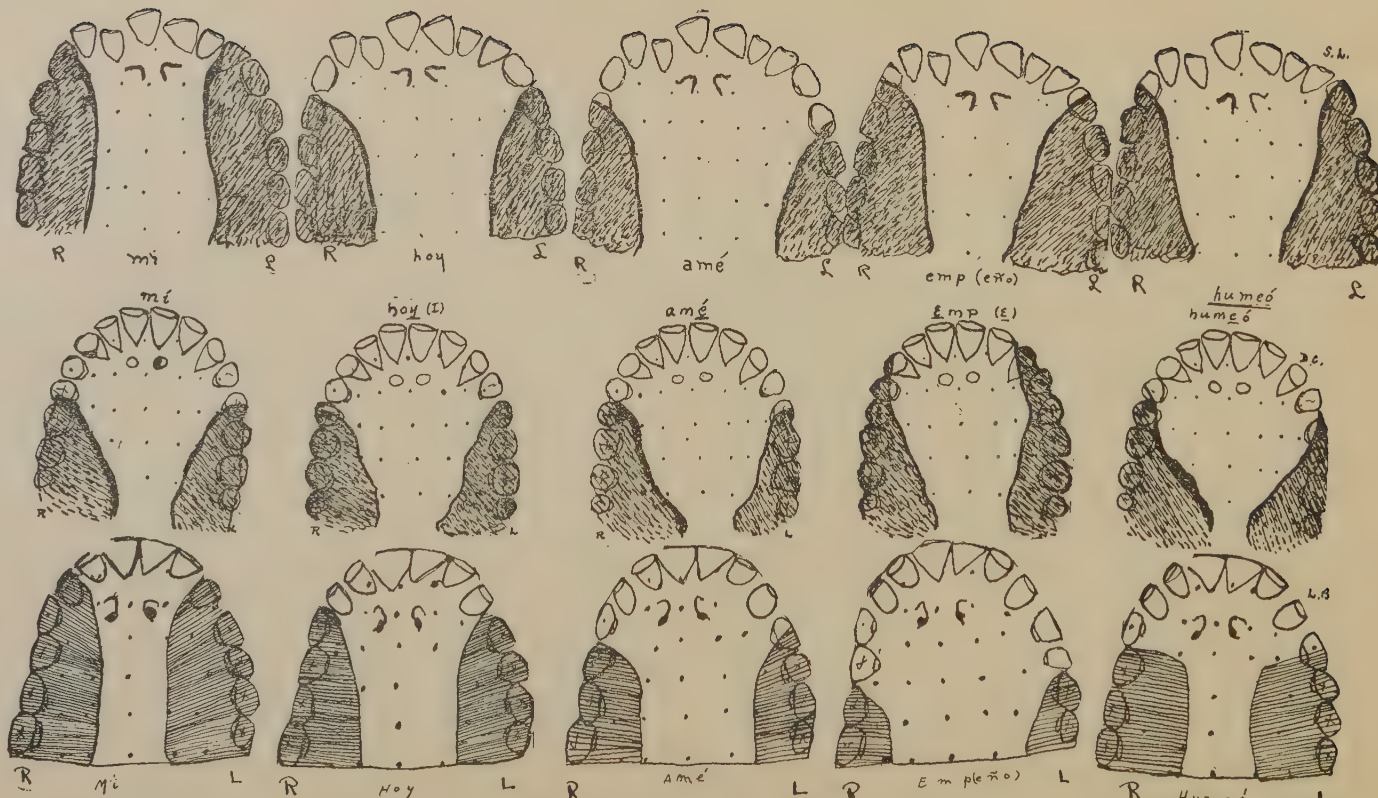
Figs. 448
453
458

carefully checked, and often rechecked where some peculiarity appeared which called for careful verification, as in Figs. 434, 436. The set contained in Figs. 419 to 423 represents the only one about which there can be any doubt.

It will be noticed that there is an astounding difference in mouths. In this series there are some who can actually pass in billiard balls, they are so wide and high. Others are very short, flat, and narrow. Such a narrow one is shown in Fig. 394, but it is high. A wide flat one in Fig. 359. A narrow flat short one in Fig. 354. One very narrow and flat in front but extraordinarily high behind in Fig. 334.

Of course it stands to reason that the results shown on subject 384 (female) compared with the one for Fig. 429 (male from the same part of the country producing a vowel which any ear will interpret as the same) showing a mouth almost twice as large as that for 384, a cavity even greater, and an opening which is comparatively the same, presents us with some very vital facts pertaining to vowel quality.

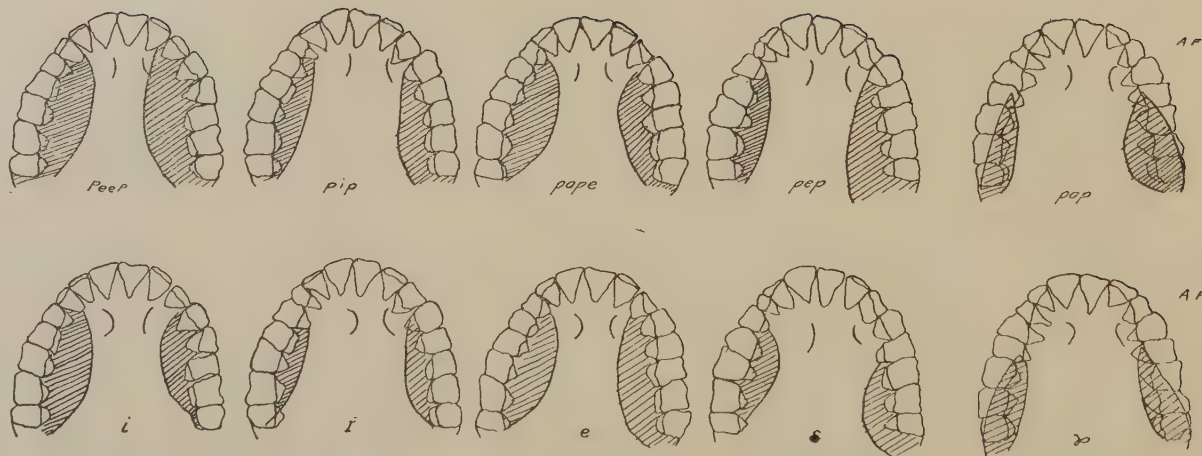
The physicist who is too often prone to jump at farfetched conclusions in regard to the physiology of speech, following non-experimental reasoning he would not tolerate in his own field, has too commonly been prone to accept Helmholtz's answer to v. Qvanten without any proof whatever. So it is quite common to note reiteration of the assertion that the difference between a male and a female, or a child and mature, vowel cavity, is compensated by the openings. A comparison of Figs. 311 and 317, will suffice to show that statement to be untrue. The wide cavity for 317 will produce a much lower pitch than the narrow cavity for 311, yet the lip-spread is so nearly alike as to fail to account for the cavity difference. As a matter of fact, it will be



Figs. 459	Figs. 460	Peruvian	Figs. 461	Spanish	Figs. 462	Figs. 463
464	465	Castilian-Cuba	466	Subject	467	468
469	470	Argentinian	471	Young Men	472	473

observed that there is not much tendency to vary the lip opening for the different vowels of rapid speech in normal every-day English. And such variation as there is appears to be more or less incidental. The author became convinced of that fact in his high-speed moving pictures of lip movement made a half decade ago while teaching at the University of Chicago one summer, and during the first of these moving picture X-ray experiments carried on in Paris, France. It was so evident, that the expense of publication was not justified.

These observations of course cast doubt on the cavity tone theories where they postulate that the total air volume formant, or resonator influence, suffices to serve as a complete explanation of vowel quality differences. For that reason this study has sought to intimate other possible influencing factors, and has repeatedly called attention to the manner in which the surfaces might function — how they might change the quality of the vowel thru favoring or damping the partials present in the glottal complex. And how great tension or a decided arching of the tongue against the hard palate might well be responsible for a certain "ringing" or "metallic" quality in such vowels as the *i* (ee). Whereas the opposite, or relaxation of the muscles and less constriction against hard surfaces could conceivably operate to "mellow" or "deaden" the tone, as it is heard in such vowels as the ɪ (pip) or ɛ (pep). This question has been considered in the preceding chapters and experimental evidence was cited in the author's "Speech and Voice" (Macmillan). All of that is involved in the theories and terminology which we are now to consider.



Figs. 479
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Figs. 480
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Figs. 481
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Figs. 482
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Figs. 483
488

Reduced by ½ a sare all Palatograms herein

The palatograms on Pages 320, 344, and 346, contain experiments showing the actual articulation, rather than the conventionalized theoretical tongue position which most published palatograms show for the so-called "palatal" *j* or "yod." It will be seen that the physiological theory is wrong, for Fig. 322 shows a wider cavity than 323; and 316 than 311; or 493 than either 489 or 491; or 517 than 512; and 523 than 506. Only 511 conforms. It may be said that friction or buzz sounds added to the vowel *i* creates that "yod." This may sometimes be created solely by increased breath pressure; other times by raising the tip of the tongue as in Figs. 523 and 505-b; at others by a mere pressing in of the saliva. So the term "palatal" is a misnomer and false in its theory implications and should be discarded. The term "yod" which refers to an acoustic fact is so much more reliable and sensible.

Narrow and Wide

The narrow-wide theory, at least as used by modern writers, appears to stand as a somewhat hazy conception in the minds of most users. If it had been properly applied it might conceivably have had some foundation on the laws of physics which might be used to account for vowel quality.

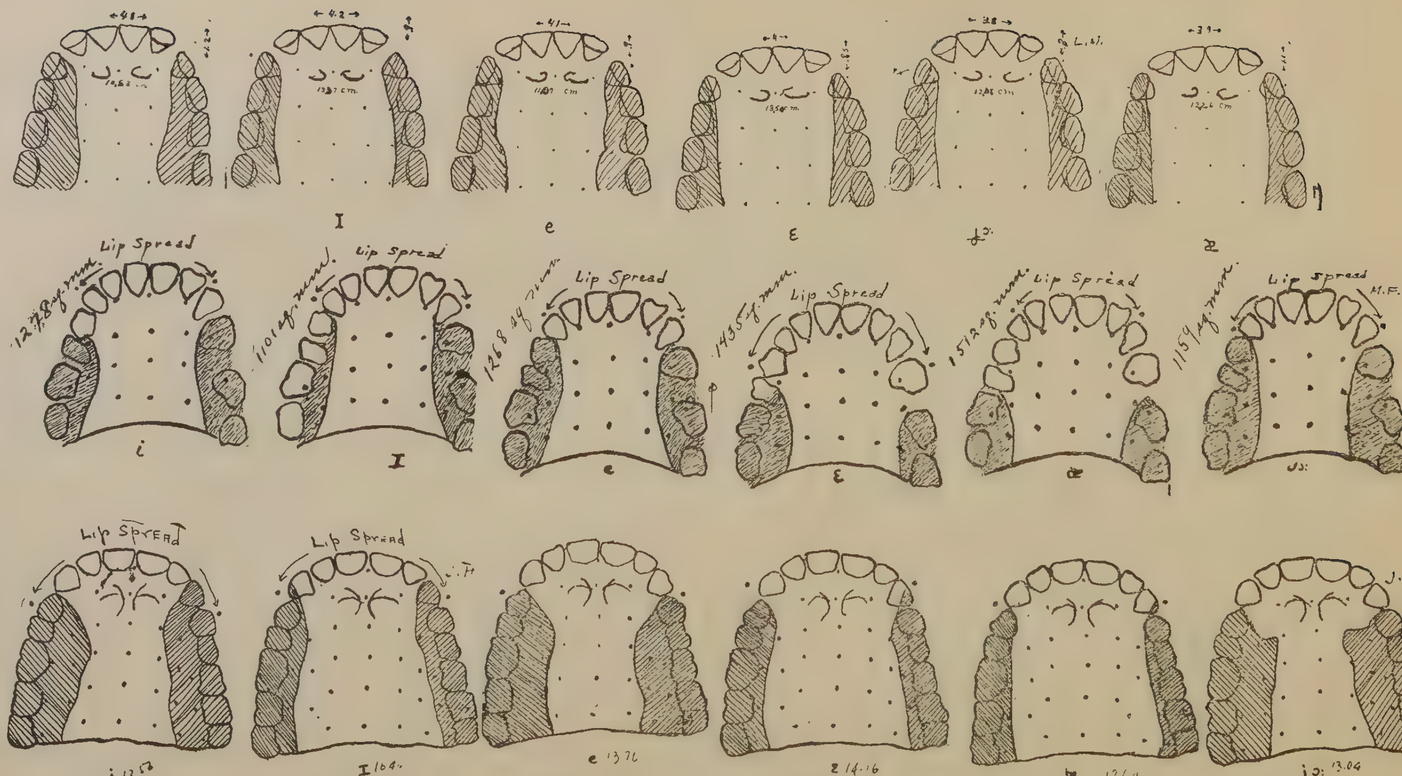
It is readily seen that so far as the cavity itself is concerned, its lateral dimensions might represent quite as important a factor in altering its characteristic tone, as would the perpendicular. And since that is the idea most commonly implied in the usage of the terms, we may accept it for purposes of our consideration, and see whether the tongue position manifest in the pronunciation of a large number of subjects bears out the theory in so far as the above five vowels are concerned. The conclusions we reach in our analysis of these front vowels, will make it unnecessary for us to study the back vowels separately, and this simplifies our task for their lateral tongue positions are not so readily recorded as are those of the front vowels.

So far as these dimensions and their influence on the cavity tone are concerned, it at once becomes evident that the physics of the problem before us calls for a study of the average diameter of the cavity as a whole. For that reason we may rule out the consideration of the point of narrowest opening for the time being, even tho this is the factor embryo phoneticians so often stress. For us the average width becomes the important factor; for the law of physics involved, states:

(1) If the average width is great the cavity pitch is lower

(2) If the average width is small the cavity pitch is higher

where the cavity is considered as functioning as a bottle with a long neck of the type dealt with in the formula on page . . . of Chapter XIII above.



Figs. 489
495
501

Figs. 490
496
502

Figs. 491
497
503

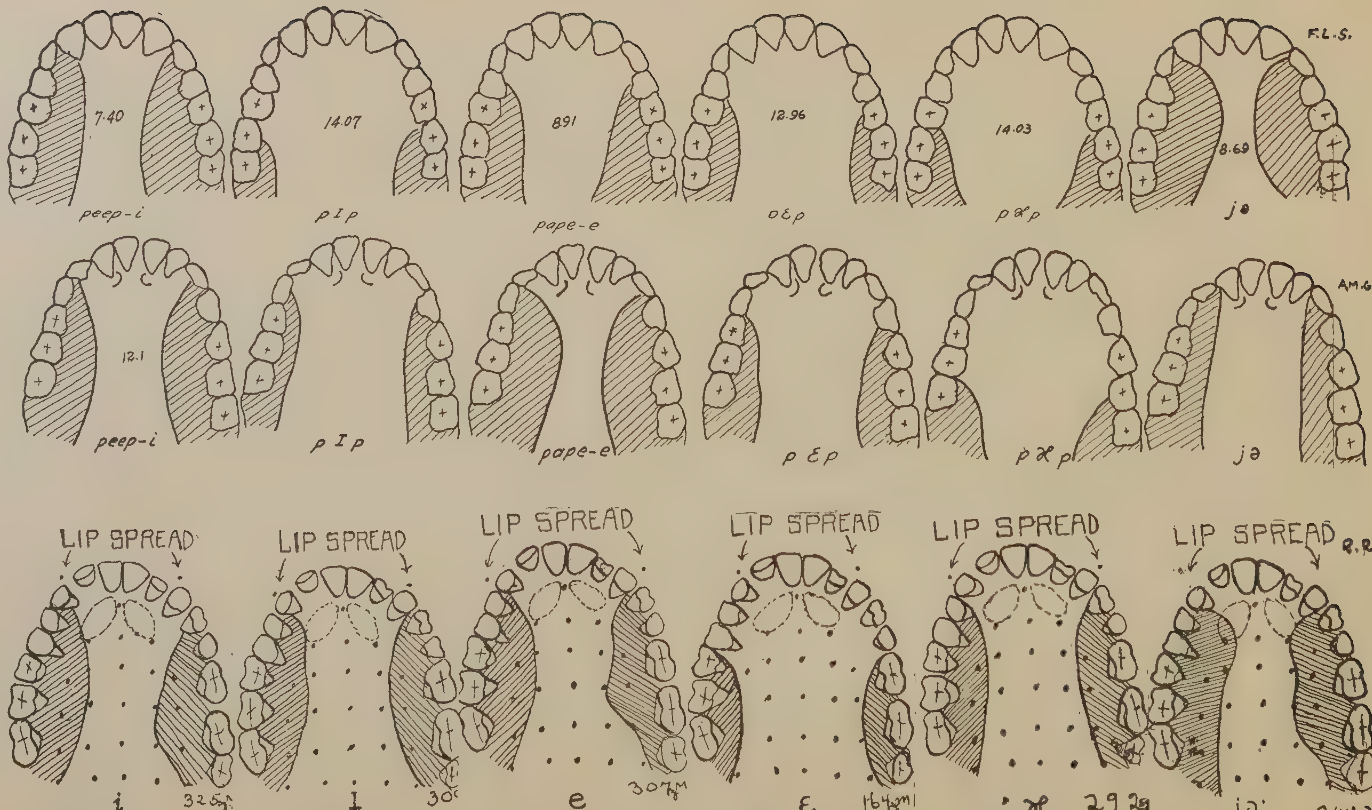
Figs. 492
498
504

Figs. 493
499
505

Figs. 494
500
505-b

It will at once be evident that for the vowel *i* (ee) which is always given as the first on the left of each plate, the "narrowest" cavities used by the various subjects are manifest in Figs. 311, 329, 359, 389, 404, 469, 479, 506, and 530. But what a difference there is! We need only compare the position taken by one subject in Fig. 329 with that of another (from the same part of the country speaking the same language, with the same unmistakable vowel quality) in Fig. 334 right under it.

It would take a better imagination than the author posseses to see any justification for ascribing the cause of vowel quality differences to this imaginary "narrow" and "wide" distinction. In the whole series, we have no vowel which is relatively "wider" than that produced in Fig. 334 for *i* (ee), except of course those where no contact with the palate took place at all. And about the same thing might be said of Fig. 339 right under it. Others which are also very "wide" are seen in Figs. 317, 369, 379, 424, 429, 434 by the same subject; 459, and 464 for Spanish rather than English; 484, 489, 495, 501, and 535. We need not add to that observation by noting that any one vowel very often shows a cavity, which is much "wider" or "narrower" in comparison with other vowels, than it is supposed to be. This is especially noticeable in a comparison of the *I* (pip) series in the second row from the left, with the *e* (pape) series in the third row from the left. We see at a glance that it is quite common to pronounce an *I* (pip) with a cavity which is "wider" than that for *e* (pape) — the exact **opposite of what the narrow-wide theory postulates.** Compare Figs. 302, 303; 307, 308; 345, 346; 355, 356; 312, 313; 360, 361; 365, 366; 380, 381; 385, 386; 400, 401; 410, 411; 415, 416; 420, 421; 425, 426; 440, 441; 445, 446; 455, 456; 480, 481; 485,



Figs. 506
512
518

Figs. 507
513
519

Figs. 508
514
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Figs. 509
515
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Figs. 510
516
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Figs. 511
517
523

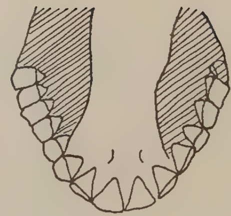
468; 490, 491; 402, 503; 507, 508; 519, 520. The exceptions are noted in Figs. 330, 331; 335, 336; 375, 376; 405, 406; where the *I* (pip) takes a noticeably "narrower" cavity than *e* (pape). So as a matter of fact, it would appear that the *I* (pip) is regularly "wider" than the *e* (pape); and the few cases in which it is clearly not, and the others where they are almost identical in lateral cavity dimension, might well be considered exceptions.

Tense and Lax

This observation might not be without significance. It confirms the same manifestation noted in the median section, or perpendicular X-ray tongue position photographs. That is the *I* (pip) quite regularly shows as more "open" than the *e* (pape). In comment on this observation, it will be remembered we called attention to the possibility that variation in surface tension of the muscular walls of the cavity, might well account for certain quality differences in certain vowel pairs. For soft surfaces tend to militate against the carrying out into space of the high-pitched "metallic" partials in a complex tone which is passed thru such a "filter." And hard walls favor the "metallic" high-pitched partials, thus resulting in a tone which is analogous to that induced when we strike a piano string with a wooden or metal hammer; whereas the soft surfaces operate to "mellow" or "deaden" the tone, in such a way as to impress the ear with a quality analogous to that heard when the same piano string is struck with a soft felt hammer.

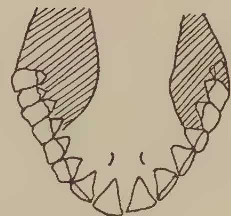
So this enlarged cavity both in median, as well as lateral dimensions, for *I* (pip) as compared with *e* (pape) might be considered as symptomatic of a relaxation, therefore possibly affecting the glottal com-

Isolated Prolonged Vowels. Below same in words



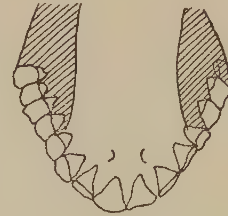
i

Fig. 525



I

Fig. 526



e

Fig. 527

ɛ

Fig. 528

L.M.

æ

Fig. 529

peep
Fig. 530

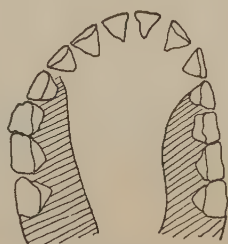
pip
Fig. 531

pape
Fig. 532

pep
Fig. 533

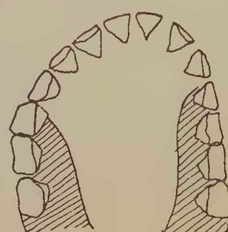
L.M.

pap
Fig. 534



i-peep

Fig. 535



I-pip

Fig. 536

e-pape

Fig. 537

ɛ-pep

Fig. 538

A.F.O.

æ-pap

Fig. 539

plex tone so as to alter vowel quality, by damping the higher partials. And the opposite may hold true, viz. that the "narrower" cavity for *e* (pape) may indicate a muscular tension which would result in a more "ringing" or "metallic" tone, than for *ɪ* (pip) or ɛ (pep). In that event the narrow and wide cavities would be purely incidental factors resulting from the muscular tension variation.

Were that true, there might be justification for the usage of the terms "tense" and "lax." But the *ɪ* (pip) would be said to be more "lax" than either the *e* (pape) or *i* (peep); and the terms "tense" and "lax" could only be applied to distinguish between the vowel pairs

i (peep) compared with the *ɪ* (pip) and
e (pape) compared with the ɛ (pep).

In that sense the terminology would be analogous to the expressions "closed" and "open" or "narrow" and "wide." But the analogy breaks down in its application to the "back" vowels, for the so-called "open" ɔ (Otto) would be more "tense" than the so-called "close" *o* (tone); or if you will have it so, the first or ɔ (otto) would be more "ringing" or "metallic" in quality in consequence of having present more high-pitched "piercing" partials than the *o* (tone).

In this country, Tomás Navarro Tomás's use of the term "relajada" has come to be generally interpreted to mean "relaxed," or "lax." The three Spanish speaking native subjects were therefore called upon for an experiment which would record this lateral position of the tongue in their pronunciation of the ɛ in "hum*e*ó" shown in Figs. 463, 468, and 473. It will be noted that quite the opposite is manifest. For 463 is much narrower than 461; and 473 radically narrower than any other vowel in the series for that subject except 469; whereas no essential difference which would account for the

vowel quality is manifest between any of those Figs. from 464 to 468. This physiological interpretation of the term is therefore indicated to be of doubtful importance.

In any event, however, the application of these terms "tense" and "lax" would have to be considered as more or less unreliable from the fact standpoint. For we have but a limited few facts upon which to base any such theory. And even if we generalized their application, we might in the long run discover that the theory involved was quite as fantastic as that represented in the terms "open" and "closed," and finally have to reject them. For that reason the author does not favor the use of the physiological terms either "tense-lax, narrow-wide, or open-closed." They are all based upon pure theory, and any classification should be founded on fact where in any way possible.

Acoustic Terms Preferable to Physiological. Metallic-Mellow; Ringing-Dull; High Pitched-Low Pitched; Recommended.

The acoustic distinction between the vowel qualities represents a substantial fact. We can take Navarro-Tomás's word for the distinction involved in the separation of the vowels classified as "relajadas." If all Spanish investigators hear them, they must exist; but should they not be classified in terms of what those scholars hear—on the basis of known facts represented in acoustic perception, stating one, to be lower or higher pitched, more or less "dull" (mellow) than the other — rather than on the basis of doubtful physiological theory?

There can be no question of doubt that the ear makes a clear distinction between the vowel quality heard when an *i* (peep) is pronounced so as to be compared

with the *I* (in pip). And that quality distinction is undoubtedly analogous to that we hear in the "metallic" tone of the piano string, as compared with the "mellower" tone produced by a softer hammer. All ears hear a certain variation in pitch and quality as such, if it is present in their native language. And so this acoustic perception represents a fact foundation, on which we can base any classification which conforms thereto. That is the reason why the author prefers it to any of our more or less fantastic physiological terms; and very earnestly recommends to the reader the advisability of using acoustic terms which stand for known facts wherever possible, in lieu of the now more or less current physiological expressions which the present study has apparently proved to be generally fantastic and practically without basis in fact.

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